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TARGET DETECTION EXPERIMENT - CANSO BANK, 1988
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PREPARED FOR THE TRANSPORTATION DEVELOPMENT CENTRE, POLICY AND CO-ORDINATION GROUP, TRANSPORT CANADA

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16. Abstract

A search and rescue target detection experiment took place off Nova Scotia on the Canso Bank in November and December, 1988 using the CCGS "Alert" and the CCGS "Sir William Alexander" as search vessels and four- and six-man orange canopied life raft targets. Daylight visual, night visual searches for canopy lights, and night vision goggle searches for illuminated and unilluminated targets were carried out and airborne radar searches were also undertaken. Human factors observations were also made on board the ships. The results suggest an improvement in search effectiveness can be achieved through lookout training and locating lookouts on the monkey island. Night vision goggle search results were in line with previous results. Negative results against unilluminated targets indicate that problems were created by the motion characteristics of the CCGS "Alert". There was no significant difference in the visual detection performance against four-and six-man life rafts. As a result, the improved detectability of DND six-man yellow canopied life rafts in 1987 is believed due to their colour. The Litton APS-504 (V) 5 search radar was the only airborne radar tested which had valid detections with a resultant sweep width of 5.25 nautical miles. A number of recommendations are made regarding operational searches and further research.

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16. Résumé

Des opérations expérimentales de recherche et de sauvetage (R&S) ont été menées en novembre et en décembre 1988 au large des côtes de la Nouvelle-Ecosse (Banc de Canso), à bord de deux navires de la Garde côtière canadienne, le Alert et le Sir William Alexander. Les cibles étaient des radeaux de sauvetage 4 et 6 places équipés d'une tente de couleur orange. Des recherches visuelles diurnes, et nocturnes (radeaux éclairés), des recherches avec lunettes de vision nocturne (radeaux éclairés et non éclairés) et des recherches par radar aéroporté ont été effectuées. Des observations à caractère ergonomique ont également été faites à bord. Les résultats montrent que l'efficacité des recherches peut être accrue par la formation des vigies et par le placement judicieux de celles-ci dans la passerelle haute. Les résultats des recherches à l'aide des lunettes de vision nocturne cadrent bien avec les résultats antérieurs. L'échec des recherches visant les cibles non éclairées est attribuable aux caractéristiques d'instabilité du Alert. Aucun écart significatif de performances n'a été constaté dans le repérage visuel des radeaux de 4 et de 6 places. Il en ressort que la plus grande détectabilité des radeaux réglementaires 6 places à tente jaune de la Défense nationale, constatée en 1987, est attribuable à la seule couleur de la tente. Le seul radar aéroporté essayé ayant donné des résultats valables a été le modèle APS-504 (V) de Litton, qui a donné une largeur de ratissage de 5,25 milles marins. Diverses recommandations sont faites en ce qui concerne les opérations de R&S ainsi que la poursuite de la recherche.

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EXECUTIVE SUMMARY

A search and rescue (SAR) detection experiment was undertaken in the fall of 1987 off the coast of Nova Scotia, Canada. The search platform was the Canadian Coast Guard Ship (CCGS) "Sir William Alexander". The targets were four-man orange canopied commercial life rafts and six-man yellow canopied Department of National Defence (DND) life rafts. Sweep widths were derived for daylight visual searches, night visual searches for life raft canopy lights, night vision goggle searches for unilluminated targets, marine radar searches for life rafts with and without radar reflectors, and marine radar searches for SAR radar transponders deployed in the water. As a consequence of the results of this experiment, a second experiment was recommended by NORDCO Limited for 1988. This recommendation was accepted by the Canadian Coast Guard (CCG) and the Transportation Development Centre (TDC), Transport Canada. This report gives details of the 1988 SAR experiment. The objectives of the experiment were:

1. Obtain visual sweep widths for large relatively unstable and more typical SAR vessels (60 m and larger) against four- and six-man life rafts and, as a result, determine the effect of stability on sweep width;

2. Determine whether colour or size was the significant factor contributing to the greater sweep widths for six-man yellow life rafts;

3. Obtain more night visual sweep width data for life raft canopy lights;

4. Obtain visual sweep widths for four - and six-man life rafts in low visibility conditions;

5. Obtain sweep width data for night vision goggles against illuminated and unilluminated four- and six-man life rafts and clearly identify operational problems associated with their usage;

6. Obtain a larger data set and hence a more accurate measure of the sweep width for SAR radar transponders;

7. Obtain a small amount of detection data using an airborne search radar against enhanced and unenhanced life rafts to identify the problems associated with undertaking a major airborne radar detection experiment; and,

8. Identify critical human factors as they affect a ship's search performance.

The 1988 field experiment was carried out between November 4 and December 11, 1988 on the Canso Bank, off Nova Scotia, using the CCGS "Alert" and the CCGS "Sir William Alexander" as search vessels. The United States Coast Guard (USCG) supplied night vision goggles and two LORAN-C buoys and participated in the airborne radar detection experiments through the provision of a HU-25A aircraft equipped with a Side-Looking Airborne Radar (SLAR) and a Forward-Looking Airborne Radar (FLAR) or search radar. An Atlantic Airways Limited aircraft equipped with a Litton Systems Canada Limited APS-504(V)5 search radar was also used in the experiment. Moored four and six-man orange canopied life rafts, and six-man yellow canopied life rafts, were used as search targets.

Vessel problems and weather restrictions limited the number of shipborne searches carried out. A total of seven daytime visual searches and one nighttime visual search were conducted, plus seven searches using night vision goggles. Between December 6 and December 8 the USCG conducted three airborne radar searches. Five radar searches were conducted using the Atlantic Airways aircraft.

Following completion of the field experiments, data reduction and analysis was carried out, together with preparation of a draft final report. The analysis methodologies employed were the same as those used by the USCG. Because of vessel problems and weather restrictions only a small data set was collected. Therefore, the results obtained for the ship searches may not be representative. This should be borne in mind when considering the results obtained.

Sweep widths for the "Alert" daylight visual searches were found to be dependent on lateral range, visibility, and wind speed. The sweep widths were found to be statistically significantly greater than those obtained for the "Sir William Alexander" in 1987. No significant difference was found between the four- and six-man orange canopied life rafts. This indicates that the greater detectability of the six-man yellow canopied DND life rafts found in the 1987 experiment was due to their yellow colour and not their size.

The daylight visual searches conducted on the "Sir William Alexander" were undertaken with the lookouts positioned on the monkey island. Lateral range and wind speed were found to be significant. Visibility was not significant because it was constant throughout the searches. Statistically there was no significant difference between the detection performance of the "Sir William Alexander" in 1988 and the "Alert"; however, at the 90 percent confidence level the "Sir William Alexander" (monkey island) had a significantly greater detection performance than the "Sir William Alexander" in the 1987 experiment in which the lookouts were placed on the bridge.

The results obtained for the daylight visual searches are based on very small data sets, but, if they are considered valid, the following conclusions can be drawn. The "Alert" lookouts used in 1988 were used in

the 1987 experiment and were essentially "trained" by this previous experience. This effect is considered to have overwhelmed the somewhat lower height of eye and livelier motion characteristics of the "Alert" in comparison to the "Sir William Alexander". The lookouts employed on the "Sir William Alexander" in 1988 and located on the monkey island were untrained. Again the "Alert" lookout training overwhelmed the positive effect of locating the lookouts on the monkey island. The lookouts used on the "Sir William Alexander" in the 1987 and 1988 experiment were all untrained. The improvement in performance in 1988 is considered to be caused by locating the lookouts on the "Sir William Alexander" monkey island.

Only one night visual search for life raft canopy lights was undertaken and this was done from the bridge of the "Alert". Only two detections were made at very short ranges. Whilst this small amount of data is insufficient to support any meaningful conclusions, the small number of detections might be, in part, a result of the relative lively motion characteristics of the "Alert".

Night vision goggle searches were undertaken against life raft canopy lights and unilluminated targets. There were an insufficient number of detections against unilluminated targets to derive a sweep width for the "Alert". The "Sir William Alexander" (lookouts on monkey island) had a 1.1 nautical mile (nmi) sweep width which was a function of lateral range only. This compares well with the 1987 result (1.3 nmi) for unilluminated targets. For illuminated targets the "Alert" and "Sir William Alexander" had sweep widths of 2.9 and 3.3 nmi, respectively. Both were a function of lateral range only. The reduced performance of the "Alert" may have been due to its livelier vessel characteristics and/or problems created by utilizing the night vision goggles from inside the bridge as opposed to on the monkey island.

The USCG airborne radars had no valid detections and hence a 0.0 sweep width against the life raft targets with radar reflectors inside. The FLAR was probably flown at a non-optimum altitude for this purpose. The Atlantic Airways Litton APS-504(V)5 radar had a 5.25 nmi sweep width which was a function of lateral range only. Targets could not be detected in sea clutter in the near range, and physical obscurity of the target by waves in the far range limited long range detection. The maximum antenna rotation rate for this radar installation was 30 revolutions per minute (r/min). Had the rotation rate been the maximum for this radar (120 r/min) the sweep width might have been substantially greater. There was a very high false detection rate on the radar and this has implications for the radar's search utility.

Two Mitsubishi Electric Corporation X-band Melsweep Model H radar transponders were utilized in the experiment; however, the battery supply of one unit was unserviceable and the other unit floated at an angle of about 30^{o}. No marine radar search data was obtained, but observed ranges of detection on the one operational unit were consistent with ranges obtained in 1987 and indicate that the sweep widths derived in the 1987 experiment are reasonably valid.

The Atlantic Airways Litton APS-504(V)5 radar was unable to detect the operational transponder during the experiment. In a special test conducted after the experiment it was found that by operating the radar is a non-optimum small target detection mode it was able to detect the transponder at ranges greater than 14.5 nmi. This has implications for airborne radar and transponder design for SAR operations.

Human factors observations were made on the "Alert" during the experiment. The bridge of the "Sir William Alexander" was inspected in port by a human factors specialist. It was observed that there was no standardized visual scanning pattern; the personnel employed may not have been a representative sample of potential lookouts; and the bridges of both the "Alert" and the "Sir William Alexander" are poorly designed and equipped for sustained visual searches. There were complaints of puffiness and watering of the eyes made by lookouts on the "Alert" after a night vision goggle search. It seems likely that the motion characteristics of the "Alert" could have been the cause.

Other observations were made during the experiment that, while not directly pertinent, are considered important in their relation to the adequacy of SAR equipment. Comments on these aspects are given in the report.

Despite the technical problems which severely limited the data collection on the "Alert", considerable knowledge was gained from this experiment. As a result, search guidance has been provided for daylight, night visual and night vision goggle searches. The most important findings are the indication that training has a significant effect on lookout performance and that positioning lookouts on the monkey island significantly increases their detection performance. Because of the major implications of these findings, it is considered imperative that a further SAR detection experiment be conducted to augment the data set for the "Alert". The experiment should be designed to verify these findings and it is important that the effect of using "trained" and "untrained" lookouts be investigated. Detailed recommendations for this experiment are given.

Sommaire

Des opérations expérimentales de recherche et de sauvetage (R&S) avaient été menées à l'automne de 1987 au large des côtes de la Nouvelle-Écosse, à bord du Sir William Alexander, un navire de la Garde côtière canadienne. Les cibles à repérer étaient des radeaux de sauvetage 4 places du commerce et des radeaux 6 places réglementaires de la Défense nationale, équipés de tentes de couleurs orange et jaune, respectivement. La largeur des circuits de ratissage a été dérivée du résultat des recherches visuelles diurnes, et nocturnes (radeaux éclairés), des recherches avec lunettes de vision nocturne (radeaux non éclairés); des recherches avec le radar de bord (radeaux avec ou sans réflecteurs radar) et des recherches avec ce même radar (transpondeurs R&S placés dans l'eau). Sur la recommandation que la Nordco Limited avait faite en 1988 à la suite de cette première expérimentation, la Garde côtière canadienne et le Centre de développement des transports de Transports Canada ont accepté de procéder à une deuxième série d'expérimentations en 1988. Le présent rapport rend compte des résultats obtenus par rapport aux objectifs suivants:

1. Déterminer la largeur des circuits de ratissage pour le repérage de radeaux de sauvetage 4 et 6 places, à bord de navires de R&S de forte taille relativement instables et d'autres plus réglementaires (60 m ou plus), et mettre en évidence l'effet de la stabilité sur les largeurs calculées;

2. Déterminer lequel des paramètres couleur ou taille explique que les largeurs de ratissage pour le repérage des radeaux 6 places ont été plus élevées;

3. Enrichir la base de données concernant les largeurs de ratissage pour le repérage de radeaux (équipés de tentes) éclairés, lors des recherches visuelles nocturnes;

4. Déterminer les largeurs de ratissage dans les recherches visuelles de radeaux 4 et 6 places dans des conditions de faible visibilité;

5. Obtenir des données permettant de calculer les largeurs de ratissage pour le repérage de radeaux 4 et 6 places, éclairés ou non, avec des lunettes de vision nocturne, et mettre en évidence les difficultés que celles-ci posent;

6. Obtenir de plus amples données permettant de calculer avec plus de précision les largeurs de ratissage pour le repérage des transpondeurs R&S;

7. Lancer une expérimentation de petite envergure sur la détectabilité au radar aéroporté des radeaux équipés ou non de dispositifs de visibilité radar dans le but de mettre en évidence les difficultés associées à une expérimentation de cette nature mais de grande envergure;

8. Mettre en évidence les facteurs ergonomiques essentiels liés à l'efficacité des opérations maritimes de R&S.

Les expérimentations menées en 1988 au large des côtes de la Nouvelle-Écosse (Banc de Canso) ont eu lieu du 4 au 11 décembre à bord des navires Alert et Sir William Alexander de la Garde côtière canadienne. La Garde côtière des États-Unis, qui avait fourni les lunettes de vision nocturne et deux bouées Loran-C, a participé aux expérimentations de repérage par radar aéroporté pour lesquelles elle a mis en oeuvre un HU-25A équipé d'un radar à visée latérale (RVL) et d'un radar aéroporté à balayage frontal (FLAR) ou radar de repérage. A également été mis en oeuvre un avion de Atlantic Airways Limited équipé d'un radar de repérage APS-504(V)5 de Litton Systems Canada Limited. Quant aux cibles, il s'agissait de radeaux ancrés 4 et 6 places à tente orange et 6 places à tente jaune.

Le nombre des opérations de recherche effectuées a dû être réduit pour des raisons techniques et météorologiques. Il s'est fait au total sept recherches visuelles diurnes et une nocturne, et sept avec les lunettes de vision nocturne. Du 6 au 8 décembre, la Garde côtière des États-Unis a effectué trois opérations de ratissage au radar aéroporté. Enfin, cinq opérations radar ont été menées à bord de l'avion d'Atlantic Airways.

A l'issue des expérimentations, les données recueillies ont été dépouillées et réduites, et un avant-projet de compte rendu final élaboré. La méthode d'analyse appliquée a été la même que celle de la Garde côtière des États-Unis. Pour les raisons techniques et météorologiques évoquées, la moisson n'a pas été riche et les résultats définitifs risquent de ne pas être représentatifs. Il ne faudra pas l'oublier lorsque viendra le moment de l'appréciation.

Les largeurs de ratissage durant les recherches visuelles diurnes à bord du Alert ont été déterminées par la portée maximale de repérage, la visibilité et la vitesse du vent. Les largeurs ont accusé un écart positif statistiquement significatif par rapport aux valeurs correspondantes obtenues à bord du Sir William Alexander l'année précédente. Aucun écart significatif n'a pu être constaté en ce qui concerne le repérage des radeaux 4 et 6 places à tente orange. Il en ressort que la plus grande détectabilité des radeaux réglementaires 6 places à tente jaune de la Défense nationale, constatée en 1987, est attribuable à la couleur de la tente et non à la taille du radeau.

Lors des recherches visuelles diurnes à bord du Sir William Alexander, les vigies se trouvaient dans la passerelle haute. Les paramètres de portée maximale de repérage et de vitesse du vent ont été significatifs, mais pas celui de la visibilité qui, elle, n'a pas varié durant les opérations. Aucun écart statistique significatif n'a pu être constaté entre les résultats obtenus à bord du Sir William Alexander en 1988 et ceux du Alert; mais au niveau de confiance de 90 p.100, les performances du Sir William Alexander en 1988 sont nettement supérieures à celles de 1987, du fait que les vigies se trouvaient placées dans la passerelle haute, et non plus sur la passerelle.

Même si les résultats des recherches visuelles diurnes proviennent d'un ensemble de données recueillies plutôt maigre, ils peuvent, s'ils sont déclarés valides, autoriser les conclusions suivantes. Les vigies à bord du Alert étant les mêmes que celles des opérations de 1987, elles ont pour ainsi dire reçu une forme de formation qui a compensé pour la plus faible hauteur d'observation et la plus grande instabilité de l'Alert par rapport au Sir William Alexander. Les vigies à bord de ce dernier en 1988 bien que placées dans la passerelle haute n'avaient pas eu cette occasion d'apprentissage. Là encore, l'expérience pratique des vigies du Alert a donné de meilleurs résultats que le fait de les placer dans la passerelle haute du Sir William Alexander. Sur ce dernier, les vigies étaient des recrues tant en 1987 qu'en 1988. Les résultats améliorés obtenus en 1988 sont attribués au fait que les vigies se trouvaient placées dans la passerelle haute.

La seule recherche visuelle nocturne de radeaux éclairés s'est faite à partir de la passerelle du Alert. Deux cibles seulement ont été repérées et ce à très courte distance. Bien que l'insuffisance des données ne puisse autoriser aucune conclusion d'importance, il semble que cet insuccès relatif soit dans une certaine mesure le résultat des caractéristiques d'instabilité du Alert.

Les lunettes de vision nocturne ont servi aux opérations de recherche visuelle de radeaux éclairés et non éclairés. Le nombre de repérages de cibles non éclairées a été trop faible à bord du Alert pour permettre d'en tirer des largeurs de ratissage. A bord du Sir William Alexander, où les vigies se trouvaient dans la passerelle haute, la largeur de ratissage calculée a été de 1,1 mille marin, valeur établie en fonction de la seule portée maximale de repérage. Cette valeur est assez proche du résultat antérieur de 1,3 mille marin, à l'égard de cibles non éclairées. Quant aux cibles éclairées, le Alert et le Sir William Alexander ont obtenu des largeurs de 2,9 et 3,3 milles marins, respectivement, fonction dans les deux cas de la seule portée maximale de repérage. La moins bonne performance du premier pourrait être due à ses caractéristiques d'instabilité et/ou à l'utilisation des lunettes de vision nocturne depuis l'intérieur de la passerelle, par opposition à la passerelle haute.

Les radars aéroportés de la Garde côtière des États-Unis n'ont réussi aucun repérage, d'où une largeur de ratissage de 0,0 mille marin à l'égard des radeaux équipés de réflecteurs radar intérieurs. Il est possible que le FLAR n'ait pas été utilisé à l'altitude optimale pour ce genre d'exercice. Le radar Litton APS-504(V)5 à bord de l'avion d'Atlantic Airways a donné une largeur de ratissage de 5,25 milles marins, fonction de la seule portée maximale de repérage. Le repérage à courte distance a été gêné par le clutter de mer, et celui à grande distance par les vagues qui rendaient les cibles invisibles au radar. L'antenne de ce radar avait été maintenue à un maximum de 30 tours/minute. A 120 tours/minute qui est le maximum pour ce type de radar, la largeur de ratissage aurait pu être bien plus grande. Le taux de faux repérages avec ce radar a été très élevé, ce qui jette un doute sur son utilité aux opérations de R&S.

Deux transpondeurs Melsweep de bande X modèle H, fabriqués par la Mitsubishi Electric Corporation avaient été mis en oeuvre. Mais l'alimentation électrique de l'un d'entre eux a fait défaut, tandis que l'autre flottait à un angle de quelque 30 degrés. La recherche au radar de bord n'a pas donné de résultat, mais les distances de repérage observées à l'égard du seul transpondeur en fonctionnement cadrent avec celles de 1987 et montrent que les largeurs de ratissage obtenues alors sont raisonnablement justes.

Le radar à bord de l'avion d'Atlantic Airways n'a pas réussi à repérer le transpondeur en fonctionnement. Mais, lors d'un essai particulier ultérieur, ce radar a réussi à repérer cette cible à des distances supérieures à 14,5 milles marins, alors qu'il était réglé à un mode non optimal de repérage de petites cibles. Cette constatation pourrait avoir des répercussions sur la conception des radars aéroportés et des transpondeurs de R&S.

Des observations à caractère ergonomique ont été faites à bord du Alert au cours des opérations de R&S, et la passerelle du Sir William Alexander a été examinée au port par un ergonomiste. Il a été observé qu'aucune trame standard de repérage visuel n'avait été adoptée, que les personnes utilisées ne constituaient pas un échantillonnage représentatif de vigies potentielles et que les passerelles des deux navires sont mal conçues et mal équipées pour des opérations de repérage soutenues. Les vigies à bord du Alert se sont plaintes, au bout d'une nuit de repérage à l'aide des lunettes de vision nocturne, d'avoir les yeux enflés et larmoyants. La cause probable pourrait en être les caractéristiques d'instabilité du navire.

D'autres observations ont été faites qui, tout en n'étant pas d'un intérêt direct, ont toutefois leur importance vu qu'elles sont liées à l'adéquation du matériel de R&S utilisé. Les commentaires qu'elles ont fait naître sont donnés dans le rapport.

Malgré les ennuis techniques responsables de la maigre moisson de données recueillies à bord du Alert, les connaissances acquises grâce à ces opérations ont été considérables, et constituent une aide utile aux recherches visuelles diurnes, nocturnes et avec des lunettes de vision nocturne. Le résultat le plus important a été la découverte du lien direct entre expérience et performances visuelles des vigies et de l'importance qu'il faut accorder au placement de celles-ci dans la passerelle haute. Les conséquences possibles de ces découvertes rendent impérative la tenue d'une autre opération de R&S dans le but d'enrichir la base de données recueillies par le Alert, de vérifier les conclusions des opérations précédentes et d'approfondir la différence entre vigies formées et non formées du point de vue des performances. Des recommandations détaillées concernant cette future opération sont données dans le rapport.

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1. INTRODUCTION

In 1987, NORDCO Limited, under contract to the Transportation Development Centre (TDC), conducted a search and rescue (SAR) detection experiment on the Canso Bank off Nova Scotia, Canada. The vessel used as the search platform was the Canadian Coast Guard Ship (CCGS) "Sir William Alexander", an 1100 class Canadian Coast Guard (CCG) buoy tender/icebreaker having an overall length of 85 metres (m), a beam of 16 m, and a displacement of 3728 tonnes. The ship was equipped with a very effective Flume Stabilization System.

The primary objectives of the experiment were to:

1. obtain visual sweep width data for Canadian SAR vessels in typical East Coast Canadian conditions;

2. add to the USCG data base on visual detection information for sea states 3 to 5;

3. determine sweep widths for standard ships' radar against unenhanced and radar reflector equipped life rafts; and,

4. determine the sweep width improvement that might be achieved using marine radars with sophisticated signal processing capability.

The targets used in the experiment were four-man orange canopied commercial life rafts and six-man yellow canopied Department of National Defence (DND) life rafts.

The major results of the experiment were as follows:

1) The sweep widths for daylight visual searches were found to be 2 to 3 times greater than those in sweep widths tables now used by the CCG.

2) The sweep width for night visual searches for life raft canopy lights was 2.2 nautical miles (nmi).

3) The sweep width for night vision goggles against unilluminated life rafts was 1.3 nmi.

4) Searches using ships radars against unenhanced life rafts resulted in sweep widths of less than 0.6 nmi.

5) Searches using ships' radars against life rafts with 2 square metre ($2\ m^2$) radar reflectors mounted at canopy height gave a sweep width of about 1.7 nmi.

6) A limited number of searches using ships' radars against life rafts equipped with radar transponders gave a sweep width of almost 9.0 nmi.

As a consequence of these results NORDCO Limited recommended to TDC and CCG that a second large scale SAR detection experiment be conducted. The objectives of the experiment were to:

1. Obtain visual sweep widths for large relatively unstable and more typical SAR vessels (60 m and larger) against four- and six-man canopied life rafts and, as a result, determine the effect of stability on sweep width;

2. Determine whether colour or size was the significant factor contributing to the greater sweep widths for six-man yellow canopied life rafts;

3. Obtain more night visual sweep width data for life raft canopy lights;

4. Obtain visual sweep widths for four- and six-man life rafts in low visibility conditions;

5. Obtain sweep width data for night vision goggles against illuminated and unilluminated four- and six-man life rafts and clearly identify operational problems associated with their usage;

5. Obtain a larger data set and hence a more accurate measure of the sweep width for SAR radar transponders;

7. Obtain a small amount of detection data using an airborne search radar against enhanced and unenhanced life rafts to identify the problems associated with undertaking a major airborne radar detection experiment; and,

8. Identify critical human factors as they affect a ship's search performance.

NORDCO Limited's recommendations were accepted by TDC and CCG. Subsequently, a second major offshore SAR experiment was conducted in the late fall of 1988 on the Canso Bank off Nova Scotia. The primary surface vessel employed was the CCGS "Alert". This ship, although comparable in size with the CCGS "Sir William Alexander", is a much livelier vessel in a given sea state. Night vision goggle units were obtained on loan from the United States Coast Guard (USCG), and two refurbished SAR radar transponders were borrowed from the CCG. The visual targets included six-man yellow canopied life rafts acquired from DND and commercial four- and six-man orange canopied life rafts.

In order to facilitate the airborne component of the work, arrangements were made to have a USCG aircraft equipped with two radar systems, and an Atlantic Airways Limited aircraft equipped with a search radar system, participate in the experiment. An ergonomics expert was contracted to make human factors observations during the experiment.

The overall project was divided into three phases as follows:

Phase I - Detailed Experiment Planning
Phase II - The Experiment
Phase III - Data Reduction, Data Analysis, and Reporting

This document constitutes the final report under the terms of the contract. It contains a detailed description of each of the phases listed above. Most importantly, this report describes the results of the experiment along with conclusions and recommendations.

2. OVERVIEW

2.1 Introduction

The project was divided into three phases to facilitate logical planning and to provide significant milestones through which progress could be clearly monitored. The activities of all three phases are summarized in the following sections.

2.2 Phase I - Detailed Experiment Planning

A detailed report on this phase is provided as Appendix A. The objectives of Phase I were:

1. identify the CCG ship to be used as the primary search platform and a support vessel if necessary;

2. identify the experiment location and time frame;

3. identify and clarify the navigation system to be used in the experiment;

4. determine the amount and type of USCG participation;

5. source the targets and related equipment;

6. designate a human factors expert and implement a plan for incorporating related observations into the experiment; and,

7. determine the aircraft availability and time scheduling for the airborne radar experiments searches using the Atlantic Airways Limited search-radar-equipped aircraft.

The results of Phase I are summarized as follows:

1) The CCGS "Alert" was selected as the primary surface search platform. The CCGS "Sir William Alexander" was selected as the support vessel for equipment deployment, maintenance and retrieval.

2) The Canso Bank was selected as the location, and the experiment, including mobilization and demobilization, was scheduled for the period of November 1 to December 18, 1988. A break in the experiment was to take place between November 25 and December 1, 1988 in order for the CCG to meet its operational requirements.

3. The same basic navigation system as used in the 1987 experiment was selected (see Dawe et al., 1988).

4. The USCG agreed to supply night vision goggles and LORAN-C buoys for the experiment. A USCG representative was to be placed on board for crew training in the use of night vision goggles and to monitor a portion of the experiment. The USCG also planned to conduct simulated radar searches using their HU-25 aircraft (Falcon jet) equipped with a forward looking radar (FLAR) and a side looking radar (SLAR), the former being a search and the latter an imaging radar.

5. Four- and six-man canopied life rafts were to be used as targets. Arrangements were made to acquire 3 DND six-man yellow canopied life rafts. Radar reflectors, to be mounted inside the life rafts for the airborne radar experiments, were also sourced. Arrangements were also made to obtain two Mitsubishi SAR radar transponders from the CCG.

6. Dr. Paul Stager of York University was designated as the human factors expert. Arrangements were made for him to spend up to a week on the search vessel during the experiment.

7. A schedule was developed for the USCG and Atlantic Airways Limited airborne radar experiments. For at least one time period the flights would overlap.

2.3 Phase II - Field Experiment

A detailed chronology of events for the experiment is provided in Appendix B. An overview of the experiment is provided here.

Mobilization of equipment for the experiment began at NORDCO Limited on November 4, 1988. The life rafts, moorings, buoys, life raft servicing equipment, and the wave measuring buoy were placed aboard the experiment support vessel "Sir William Alexander" at the CCG base in Dartmouth, Nova Scotia on November 7, 1988. The ship departed the next day for the Canso Bank, arriving the following morning. Mobilization of the "Alert" was initiated simultaneously at the Shearwater docking facility. The "Alert" proceeded to Liscombe Harbour on November 5 while the installation of receiving and display equipment continued.

On November 9, 1988 the crew of the "Sir William Alexander" commenced deploying moorings on the Canso Bank. Unfortunately during these operations a line with an anchor attached became entangled in the ship's bow thruster. The ship was forced to proceed to Mulgrave, Nova Scotia in order to have divers remove the line. The "Alert" joined the "Sir William Alexander" in Mulgrave.

On November 10 the "Sir William Alexander" departed Mulgrave for the Canso Bank to continue its mooring operations. The "Alert" proceeded to Country Harbour to await the completion of the deployment work. The "Sir William Alexander" completed its work that evening and transferred the NORDCO staff to the "Alert" in Country Harbour. It then returned to Dartmouth.

Gale force winds on November 11 prevented the "Alert" from doing any work that day.

On November 12 the "Alert" proceeded to Canso Bank. The seas were too rough to deploy life rafts and instead the day was spent checking the navigation system. The LORAN-C buoy was found to be working incorrectly.

The LORAN-C buoy was recovered and reset on November 13 but it was still operating incorrectly. Its received signal was subsequently removed from the navigation system. On the same day the first life raft deployments took place and the first night vision goggle search for illuminated targets was initiated.

Searches continued until the early evening of November 15, at which time the "Alert" departed for Mulgrave to facilitate crew changes. The inner seal of the stern tube on the port shaft became unserviceable while docking at Mulgrave.

In order to facilitate Atlantic Airways airborne radar searches planned for November 18 to 24, two NORDCO staff members departed from the "Alert" at Mulgrave and travelled to Dartmouth to join the "Sir William Alexander". This ship departed Dartmouth on the evening of November 16 for the Canso Bank and on the 17th serviced the life rafts and changed out the LORAN-C buoy in preparation for the first airborne search which took place late that afternoon.

On November 18 a second airborne radar search was planned but had to be cancelled because of problems with the aircraft navigation system. Later that day the "Sir William Alexander" was assigned to a SAR mission which lasted into the next evening.

On November 19 a test of a shaft seal repair on the "Alert" was undertaken with the result that the repair was found acceptable. The ship proceeded to Country Harbour to await the arrival on the following day of NORDCO personnel and the human factors expert, Dr. Stager.

The "Sir William Alexander" departed Mulgrave on November 20 and proceeded to the Canso Bank to retrieve all life rafts in advance of a developing storm system. The "Alert" remained in Country Harbour.

On November 21, after reviewing the weather situation for the next five days, it was decided to terminate the first half of the experiment early and all NORDCO personnel and the Atlantic Airways aircraft departed for St. John's, Newfoundland. Dr. Stager returned to Toronto.

The second half of the experiment commenced with the "Sir William Alexander" departing Dartmouth for the Canso Bank on December 2. Its crew began deploying targets upon arrival on the Bank. The "Alert", which was holed above the waterline while docking at Shearwater on December 1, was unable to depart until very late on December 2. Dr. Stager, along with the NORDCO crew, sailed with this ship.

The "Alert" was made available to the experiment only for another 48 hour period because of further problems with the leaking shaft seal. It was only able to travel at reduced speed because of this problem and arrived in the experiment area mid-afternoon on December 3. Searches were conducted for the next two days. The "Sir William Alexander" remained in the general area to service targets. On the afternoon of December 5 the "Alert" left the Canso Bank area for Mulgrave. The "Sir William Alexander" retrieved all the targets and followed the "Alert" into Mulgrave.

During the evening of December 5 all NORDCO personnel and equipment were transferred to the "Sir William Alexander". This ship was to be used for the remainder of the experiment and would provide support for airborne radar searches and as well as to conduct surface searches. It sailed for the experiment area on December 6 to deploy targets and prepare for the first airborne search. Dr. Stager left the ship during this change over.

The USCG aircraft equipped with a real aperture Side-Looking Airborne Radar (SLAR) and a Forward Looking Airborne Radar (FLAR) arrived at the Shearwater DND Base on the morning of December 6, 1989. That afternoon, and throughout the following day, three simulated airborne radar searches were conducted by the aircraft. It returned to the United States after the last search.

The Atlantic Airways Limited aircraft, equipped with an airborne search radar, departed St. John's for Halifax on the afternoon of December 6. A simulated radar search was to be conducted enroute but equipment problems resulted in the search only being about twenty minutes long. The aircraft arrived that evening in Halifax International Airport. Over the next two days four more radar searches were undertaken with this aircraft.

As well as supplying surface support to the airborne search, the "Sir William Alexander" undertook night vision goggle searches and daylight visual searches. These continued into December 9. At that time, because of the deteriorating condition of the targets, problems with freezing spray and ice accumulation, and other problems, it was decided to terminate the experiment. Over the next 24 hours (h) the "Sir William Alexander" recovered all the moorings and departed for Dartmouth, arriving there the night of December 10. On December 11 demobilization of the vessel commenced. It was completed the following day and the last of the NORDCO personnel departed for St. John's.

Table 1 shows a summary of the number and type of searches undertaken during the entire experiment. A more detailed summary of the environmental conditions for each search is provided in Appendix C.

2.4 Phase III - Data Reduction, Analysis, and Reporting

Following completion of the field work, the field data containing the detection reports and the environmental observations were assembled and reviewed, then, following an initial quality control check, entered into disk files on the NORDCO Limited DEC VAX 11/750 computer system. Following

further quality control checks, analysis of the detection data was carried out. The analysis methodology is described in Part 4 and the results are provided in Part 5. The conclusions and recommendations are given in Part 6.

SEARCH TYPE	NUMBER OF SEARCHES	SEARCH TIME (h)	TARGET OPPORTUNITIES	TARGET DETECTIONS	WIND SPEED (kt)	SIGNIFICANT WAVE HEIGHT (m)	PREVAILING VISIBILITY (nmi)	CLOUD COVER (tenths)
VISUAL SEARCHES								
Alert:								
Daytime	5	19.2	74	24	18-33 (26)	2.0-2.7 (2.5)	5-15+ (13)	3-10 (5.4)
Night	1	6.2	18	2	30-39 (34)	2.8-3.2 (3.1)	1/4-8 (6.7)	6-10 (8.2)
Sir William Alexander:								
Daytime-Monkey Island	2	5.8	32	13	15-34 (23)	1.6-2.4 (1.9)	15+ (15+)	2-7 (5)
ELECTRONIC SEARCHES								
Alert:								
Night Vision Goggles: Ill. Targets	2	12.8	52	10	7-26 (17)	0.6-1.8 (1.1)	10-15+ (14.9)	2-10 (7.6)
Night Vision Goggles: Unill. Targets	3	12.2	43	3	20-31 (25)	1.4-3.2 (2.3)	6-15+ (13.4)	6-10 (8.3)
Sir William Alexander:								
Night Vision Goggles								
- Bridge: Unill. Targets	1	2.3	19	0	22-32 (27)	2.5-2.8 (2.7)	10-15 (13.1)	1-9 (3.3)
- Monkey Island: Ill. & Unill. Targets	1	4.8	24	7	12-20 (14)	1.2-1.3 (1.2)	15+ (15.0)	1-9 (7.3)
AIRBORNE RADAR SEARCHES								
Atlantic Airways	4	6.5	174	29	12-34 (23)	1.2-3.0 (2.1)	N/A	N/A

NOTE: Average Conditions are shown in Brackets

Table 1 - Summary Of Searches And Associated Environmental Conditions

NORDCO LIMITED

3. DESCRIPTION OF VESSELS AND EXPERIMENT HARDWARE

3.1 Description of Vessels

The CCGS "Alert" is a Coast Guard SAR cutter built in 1969. The ship has an overall length of 71.5 m and a displacement 2200 tonnes. The height of eye on the bridge is about 10.7 m. The ship is slightly smaller than the "Sir William Alexander" which has a bridge height of eye of 12.7 m. The "Alert" also has much greater motion characteristics than the "Sir William Alexander". It has virtually no deck handling capability and, as a consequence, a second vessel was required during the experiment for target and mooring deployment, servicing, and retrieval.

Visual detection work was conducted from the enclosed bridge by seamen and leading seamen stationed on either side of the bridge. There were virtually no restrictions to vision caused by the superstructure through approximately 150° from the bow on either side of the ship. During night vision goggle searches, every effort was made to reduce the exterior lighting on the ship and the interior bridge lighting to the absolute minimum. Also, because of reflections and glare, the windows on the bridge at the lookout locations had to be opened whilst the night vision goggles were in use. This resulted in the bridge area being very uncomfortably cold. Occasionally, substantial amounts of sea water came in through the open windows.

During the last week of the experiment a few searches were conducted using the "Sir William Alexander". A description of this ship is provided in Part 1. The only searches for which valid data were collected involved lookouts situated on the monkey island which has a height of eye of about 15.7 m.

3.2 Search Objects and Mooring Systems

3.2.1 Life Rafts and Moorings

Four- and six-man orange canopied commercial life rafts were used in the experiment. Normally about 8 to 10 rafts were deployed at any one time. The rafts were stripped of all ancillary equipment other than the standard light mounted atop the canopy tube(s). Three six-man yellow canopied DND life rafts were obtained as well; however, these were destroyed in a storm before any searches could be undertaken using them as targets.

The mooring arrangement used to moor the life rafts was the same as that used in the 1987 experiment (Dawe et al., 1988) and is described in Appendix A. The mooring gear was provided by the Coast Guard and prepared at the CCG Base, Dartmouth, NS. It consisted of two Norwegian net floats secured by polypropylene line to a concrete block. The life rafts were secured to the moorings with a polypropylene hollow braid bridle. The line was fixed between the inflation tubes.

Of 17 life rafts used in the experiment (including the DND life rafts) only about 6 remain in good condition. Aside from the DND life rafts, a number of commercial ones were totally destroyed.

3.2.2 Radar Reflectors

Lensref omniazimuthal Luneburg lens type X-band radar reflectors were used to simulate the radar reflectivity of personnel in the life rafts. Manufactured by Tokyo Keiki Company Limited of Japan, the Lensref reflectors had a radar cross section area of around $2m^2$. This reflectivity is approximately two times the radar cross section of a man standing upright and, for the purposes of this experiment, has been assumed to be approximately equal to the radar cross section of 4 to 6 men huddled inside a life raft. The Lensref reflectors, having a diameter of 20.3 centimetres (cm) and a mass of 2.5 kilograms (kg) were deployed inside the life rafts throughout the experiment. A more detailed description of the reflectors can be found in the report on the 1987 experiment.

3.2.3 Radar Transponders

Two Mitsubishi Electric Corporation X-band Melsweep Model H radar transponders developed for search and rescue were also used in the experiment. When illuminated by X-band electromagnetic energy, such as that radiated by a standard marine radar, these transponders produce a train of 20 radar response pulses radiating outward in range from its position. These chains of pulses are clearly seen on a plan position indicator display. Again a more detailed description of the transponder can be found in the report on the 1987 experiment.

These transponders were obtained on loan from the CCG and their batteries had been replaced by the CCG. The CCG advised NORDCO Limited that since the battery change one transponder floated at a 30 degree angle instead of vertically. A test for basic operation was performed in St. John's Harbour and this confirmed that both transponders were generating a response signal.

It was initially planned to deploy these transponders to obtain additional ship's radar sweep width data. The deployment was timed to coincide with airborne radar searches. The transponder which floated properly was deployed by attaching it by a line to a life raft and allowing it to float free. The second transponder was held as a back-up. It was eventually deployed in the second half of the experiment by securing it inside a life raft.

3.3 Electronic Sensor Systems

3.3.1 Airborne Radar Systems

Detailed technical information on the airborne radar systems employed by the USCG and Atlantic Airways are provided in Appendix A. General descriptions are provided in the following paragraphs.

The imaging radar deployed on the USCG aircraft is a real aperture Motorola AN/APS-131 SLAR designed for oil spill surveillance. The radar produces images of the surface on both sides of the aircraft by making use of the forward motion of the aircraft. The images can be recorded in real time on film, or at reduced bandwidth on a video cassette recording system, or may be displayed on a television monitor. The inner edge of the image on each side normally begins at a lateral distance approximately equal to the altitude of the jet. The outer edge of each side is determined by the image swath width setting which can be a maximum of 80 nmi. The settings normally used are 10 and 20 nmi.

The basic operation of the search radars employed on both aircraft is similar to that of a marine radar, however, these radars are normally equipped with substantially more processing capability and system parameters which provide them with detection capabilities which are much greater than that of a standard marine radar.

The search radar on board the Falcon jet is the Texas Instruments AN/APS-127 FLAR. The FLAR nomenclature is a United States (US) description for a search or surveillance radar that only scans the forward 180° sector.

The Atlantic Airways Limited radar is a Litton Systems Canada Limited APS-304(V)5 search radar (US nomenclature AN/APS-140(V)). This radar, with its antenna mounted in a dome underneath the aircraft, provides 360° coverage. The advertised specifications on this radar suggests that it should perform somewhat better than the USCG FLAR, primarily due to the signal processing capability. Unfortunately, the configuration on the Atlantic Airways Limited aircraft apparently does not allow the antenna to rotate at its highest speed of 120 revolutions per minute (r/min) and is currently only operable at 30 r/min. Thus the radar is not presently operating at its optimum performance level.

The Atlantic Airways radar was operated in the mode assumed to be the optimum for searching for a target such as a life raft. This involved using the shortest pulse length, sensitivity time control, frequency agility, scan-to-scan integration, constant false alarm rate processing, and a ground stabilized display. Both 12 and 25 nmi range scale settings were used. The aircraft flew at an altitude of about 150 m. The antenna rotation rate was 30 r/min, the highest rate possible with the present configuration.

3.3.2 Night Vision Goggles

Two units each of two models of night vision goggles were made available by the USCG. One model was a binocular type (Litton Model M-915A) and the other was a monocular type (Litton Model M-972). Manufacturer's brochures of the two models are provided in Appendix D.

3.4 Navigation System

With some minor modifications, the navigation system utilized in the 1987 experiment was also employed in this experiment. It is a LORAN-C hyperbolic radio positioning system, which can be used in a differential mode when utilized in conjunction with a LORAN C buoy, moored in the centre of the experiment area. The LORAN-C time difference (TD) information for the vessel is printed and logged to a disk file on a Compaq computer every 24 seconds. When used in conjunction with the LORAN-C buoy, the 10 minute (min) average time difference transmitted via a VHF telemetry link from the buoy every 10 min is also utilized and logged on a disk file. Two Candel Industries Sea Rover 2 LORAN-C buoys on loan from the USCG were to be employed. Unfortunately, neither of these buoys were serviceable during the experiment and, because of this, the system was operated in a non-differential mode. A detailed description of the navigation system is provided in Appendix A.

3.5 Environmental Monitoring Instrumentation

3.5.1 Meteorological Data

Meteorological and sea state observations were taken hourly during all visual and electronic search operations. As well, these observations were supplemented with additional observations whenever significant changes in conditions occurred between the Greenwich Mean Time (GMT) hourly readings. The following observations and derived data were recorded routinely:

- sky condition
- prevailing visibility
- weather (eg., rain, snow showers) and obscurations to vision (eg., fog)
- cloud types and amounts
- dry bulb temperature (^{o} Celsius (^{o}C))
- wet bulb temperature (^{o}C)
- dew point temperature (^{o}C)
- relative humidity (%)
- ship's heading (^{o} True)
- ship's speed (knots)
- apparent wind direction (^{o} relative)
- apparent wind speed (knots)
- true wind direction (^{o} True)
- true wind speed (knots)
- barometric pressure (millibars (mb))
- mean sea level pressure (mb)
- sea surface temperature (^{o}C)
- estimated sea wave height (m) and period, seconds (s)
- estimated swell direction, height and period (^{o} True, m, s)
- degree of whitecapping.

Measured data were obtained using meteorological instrumentation available on board the ship. Temperatures were recorded from wet and dry bulb thermometers mounted inside the windward marine screen. The screens

were mounted on the hand rails just abaft the bridge at a height of approximately 10 m above the sea surface. The anemometer was mounted near the top of the ship's mast at a height of approximately 28 m above the sea surface. No adjustment of the wind speed to a standard height has been made; consequently, the true wind speed that was logged and subsequently used in the data analysis represents the true wind speed at the anemometer height.

3.5.2 Real Time Wave Measuring System

A Datawell wave measuring buoy was deployed near the centre of the Canso Bank in 60 m of water during the initial set-up phase of the experiment. The wave buoy transmitted spectral wave data to a Diwar receiver installed on board the ship. A Compaq portable microcomputer, provided with the system, was used to process the data collected over a 27 min period; the wave spectrum and certain wave parameters were output once every 30 min. The primary wave parameters of significant wave height and peak period of the spectrum were logged hourly along with the meteorological observations. The measured significant wave height was the value used in the detection data analysis. The wave buoy system functioned properly throughout the experiment; data were reliably received whenever the ship was within about 20 kilometres (km) of the wave measuring buoy.

4. ANALYSIS METHODOLOGY

4.1 Introduction

The analysis methodology employed for visual and night vision goggle searches was the same as that used in the previous Canso Bank experiment (Dawe et al., 1988) and followed USCG procedures for these types of experiments. It involved a multivariate regression technique to compute a relationship between various independent variables (regressors) and the probability of search object detection. In addition to lateral range, defined as the minimum distance between the position of the search object and the observer's track (often referred to as the closest point of approach (CPA)), relevant independent variables include physical attributes of the search object (for example, size and colour), observer parameters (for example, height of eye and time on task), and environmental conditions (for example, significant wave height and prevailing visibility). Sweep width, the resultant parameter used in actual search planning is determined by integrating the probability of detection with respect to lateral range for the relevant values of the significant independent variables. The concept sweep width, as explained by Koopman (1980), is interpreted as follows: the probability of detecting a search object beyond one half the sweep width, on either side of the SAR vessel, is equal to the probability of missing a target located less than one half the sweep width on either side of the search unit.

4.2 Data Reduction Methodology

The data reduction methodology involved compiling all the opportunities and detections for each search, and assigning the relevant variables to each one (for example, wind speed, wave height, visibility, etc.). This was achieved by reconstructing the ship's track for each search and utilizing the detection observations recorded during the simulated search. To achieve this the Compaq computer, originally used for logging the ship's track, was programmed to regenerate each track along with the location of each target (each opportunity). Two analysts, using this regenerated track, identified and recorded all valid opportunities and detections. This information was transferred to NORDCO Limited's main computing facility for the actual multivariate regression analysis.

4.3 Data Analysis Methodology

The maximum log likelihood model described by Cox (1970) was used to determine the probability of detection (P) as a function of a combination of a number of independent variables. The model uses the following equation:

$$p = \frac{1}{1 + e^{-\lambda}} \qquad (1)$$

where,
and,

$$\lambda = a_0 + \sum_{i}^{h} = 1 \, a_i x_i \qquad (2)$$

a_o is a constant;
a_i is the coefficient of the ith independent variable,
x_i is the value of the ith independent variable; and,
n is the number of independent variables.

The independent variables may be binary (for example, life rafts with or without canopies) or continuous (for example, wind speed). The variables are preselected and checked for their statistical significance at the 90 percent confidence level in an interactive procedure. Those variables that are not significant at the 90 percent confidence level or whose limits at the 90 percent confidence level cross zero (or in other words one limit is positive and the other is negative) are rejected sequentially, starting with that one having the lowest significance. The multivariate regression analysis is repeated after each non-significant independent variable is removed until all the remaining variables contribute significantly to the variability of λ.

Having determined λ , P, as a function of lateral range (x), can be determined at all lateral ranges for given values of the other significant independent variables. Sweep width (SW) is then computed using the relationship:

$$sw = 2 \int_0^{\infty} P(x) \, d(x). \qquad (3)$$

The foregoing analysis was undertaken using software developed at NORDCO Limited and implemented on its DEC VAX 11/750 computer.

4.4 Airborne Radar Data Analysis

Only the Atlantic Airways Limited radar data was analyzed for this report. USCG personnel assumed responsibility for analyzing the radar detection data collected on their aircraft. The analysis methodology that was employed followed, in general, USCG procedures for visual detection up to the stage of determining the relationship between various independent variables and the probability of detection. The detection records were sorted by lateral range then binned to ensure that no bins were empty. Finally, the percentage of targets detected in each bin was calculated. Plots of the percentage of targets detected versus lateral range clearly showed that the choice of an exponential model, normally used for visual detection analysis, was not appropriate for the airborne radar detection data. The detection process itself using airborne radar is entirely different from that of visual detection, and competing sea clutter in the near range will result in a bimodal probability of detection curve with a decline occurring in this near range area. In the absence of a standard method, the sweep width was determined by numerical integration using the actual binned probability of detection versus lateral range data.

5. RESULTS

5.1 Introduction

The following sections provide the probability of detection and sweep width results for the various sensor/target combinations. In all cases the multivariate regression analysis methods referred to in Section 4 were utilized.

5.2 Visual Searches

5.2.1 Daylight Visual Searches

The factors tested for significance in the multivariate regression analysis were:

lateral range,
wind speed,
sea state (significant wave height),
precipitation,
white caps,
cloud cover, and,
target type (four- or six-man life rafts).

Daylight visual searches were carried out on the "Alert" (bridge lookouts) and the "Sir William Alexander" (monkey island lookouts). In both analyses, lateral range, wind speed, and target type were found to be significant. Visibility was significant for the "Alert" only. Searches on the "Sir William Alexander" were conducted in constant visibility conditions (15 nmi) and, consequently, it was not significant. Life raft size (four- or six-man orange canopied commercial life rafts) was not significant in either case. The regression analysis technique was also used to determine whether there was a significant difference between the two vessels at the 90 percent level of significance. They were found not to be significantly different. The same test was undertaken comparing the 1988 detection performance with that of the "Sir William Alexander" in the 1987 experiment. Performance of both the ships used in 1988 were found to be significantly different from the 1987 performance at the 90 percent level of significance.

Table 2 contains a listing of the independent variables, their units, and the corresponding coefficients for daylight visual searches for both vessels. Sweep width values may be computed for any combination of these variables by determining λ using equation (2), then the probability of detection from equation (1) and, finally, by integrating equation (3).

5.2.2 Night Visual Searches for Life Rafts with Lights

Only one search was undertaken and this was done from the "Alert". Of 18 opportunities only 2 detections were made. The number of detections was too small to perform a sweep width analysis.

INDEPENDENT VARIABLE	UNITS	COEFFICIENTS	
		ALERT	SIR WILLIAM ALEXANDER (MONKEY ISLAND)
Contant Term	-----	8.40	7.71
Lateral Range	Nautical Miles	-2.30	-1.82
Visibility	Nautical Miles	0.41	N/A
Wind Speed	Knots	-0.41	-0.19

1 Visibility was not a significant variable in the "Sir William Alexander" analysis.

Table 2 – Regression Coefficients Derived From The Data Set And Used For Computation Of Daylight Visual Search Sweep Widths

5.3 Night Vision Goggle Searches

The night vision goggles were tested against illuminated (life rafts with canopy lights activated) and unilluminated targets (canopy lights off). The resultant regression coefficients and sweep widths are shown in Table 3. In all cases, lateral range was the only significant independent variable as was the result in 1987. Table 3 shows the 1987 "Sir William Alexander" result as well. Because of the small percentage of detections against unilluminated targets for the "Alert", it was not possible to establish a significant relationship with any independent variables (including lateral range) and probability of detection using the multivariate regression technique. Figures 1 and 2 show the derived probability of detection versus lateral range relationship for the "Sir William Alexander" (monkey island) and the "Alert", respectively.

5.4 Airborne Radar Searches

The factors tested for in the multivariate regression analysis of the airborne radar data were wind speed and sea state. Neither were significant. Figure 3 shows probability of detection as a function of lateral range (or CPA). The 2.5 nmi binning was selected as it best illustrated the probability of detection trend with increasing lateral range. The sweep width, derived by integrating the area under the probability of detection versus lateral range curve shown in Figure 3 and multiplying by 2, was found to be 5.25 nmi.

5.5 Transponder Detection

Due to technical problems with the transponders, no ship's radar searches were undertaken. Ranges of detection on the one operational unit were found to be between 4.3 and 8.0 nmi.

During the experiment neither of the USCG or Atlantic Airways airborne radars were able to detect the transponders. Of the two radars on board the USCG aircraft only the FLAR was technically capable of detecting the transponder as the SLAR used vertical polarization and the transponder operated on horizontally polarized energy. Also, the USCG FLAR was tested only against the transponder which operated at a very reduced power level, and then only for a portion of the experiment period.

In a special test after the experiment it was found that the Atlantic Airways radar could indeed detect the transponder only if it utilized the longer of the two compressed pulse modes and the non-frequency agile mode. While the maximum range at an altitude of 150 m was not obtained, the transponder was easily detected at 14.5 nmi.

The transponders were checked after the experiment to determine why the one transponder was not operating (very low radiated power). Initially the electronics sections of both the transponders were switched to confirm the operation of this part of the faulty unit. The result was positive. The operating transponder was found to have a battery supply voltage of 18 volts (v) while the inoperative unit had a voltage of 16 v. Although the

battery supply of the faulty unit was not tested under a load, it appears likely that the problem was caused by a low battery supply voltage.

SEARCH PLATFORM	REGRESSION COEFFICIENTS			SWEEP WIDTH(NMI)	
	CONSTANT TERM	LATERAL RANGE (NMI)	TARGET TYPE[1] ILLUMINATED(2)/UNILLUMINATED(1)	UNILLUMINATED TARGETS	ILLUMINATED TARGETS
Sir William Alexander 1987	-0.25	-0.95	N/A	1.3 (43/6)[2]	N/A
Sir William Alexander 1988 (Monkey Island)	-2.90	-1.71	3.34	1.1 (15/2)	3.3 (9/5)
Alert, 1988	1.34	-1.13	N/A	--- (43/3)[3]	2.9 (52/10)

1 This variable only applies to the Sir William Alexander, 1988, data set for which the one search included both types of targets.

2 This is the total number of opportunities/total number of detections.

3 The regression analysis failed because the detection percentage was too low.

Table 3 – A Comparison Of Regression Coefficients And Resultant Sweep Widths For Night Vision Goggle Searches

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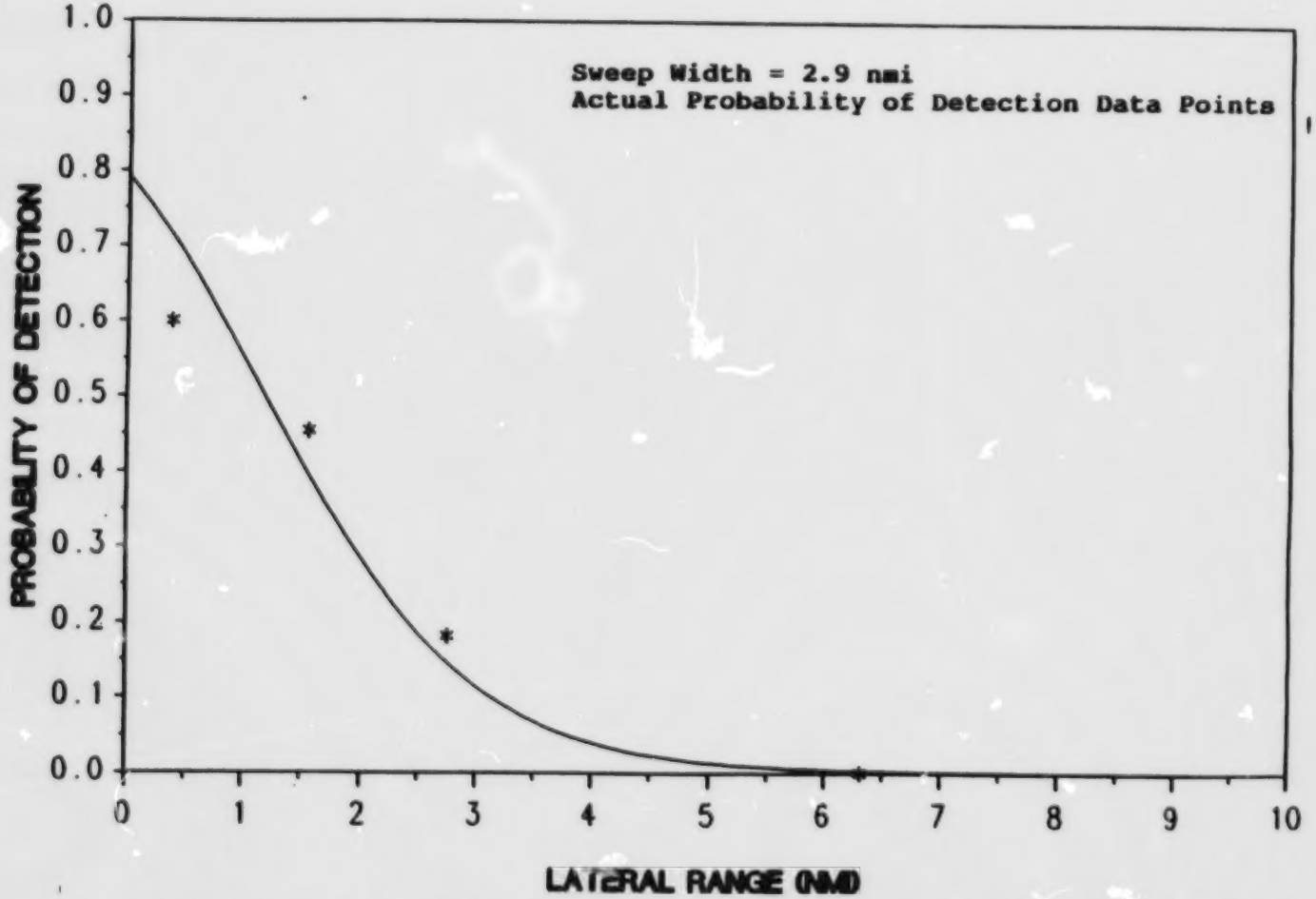

Figure 1 - Probability Of Detection Versus Lateral Range Derived From Night Vision Goggle Searches For Life Raft Canopy Lights Using The CCGS "Alert"

NORDCO LIMITED

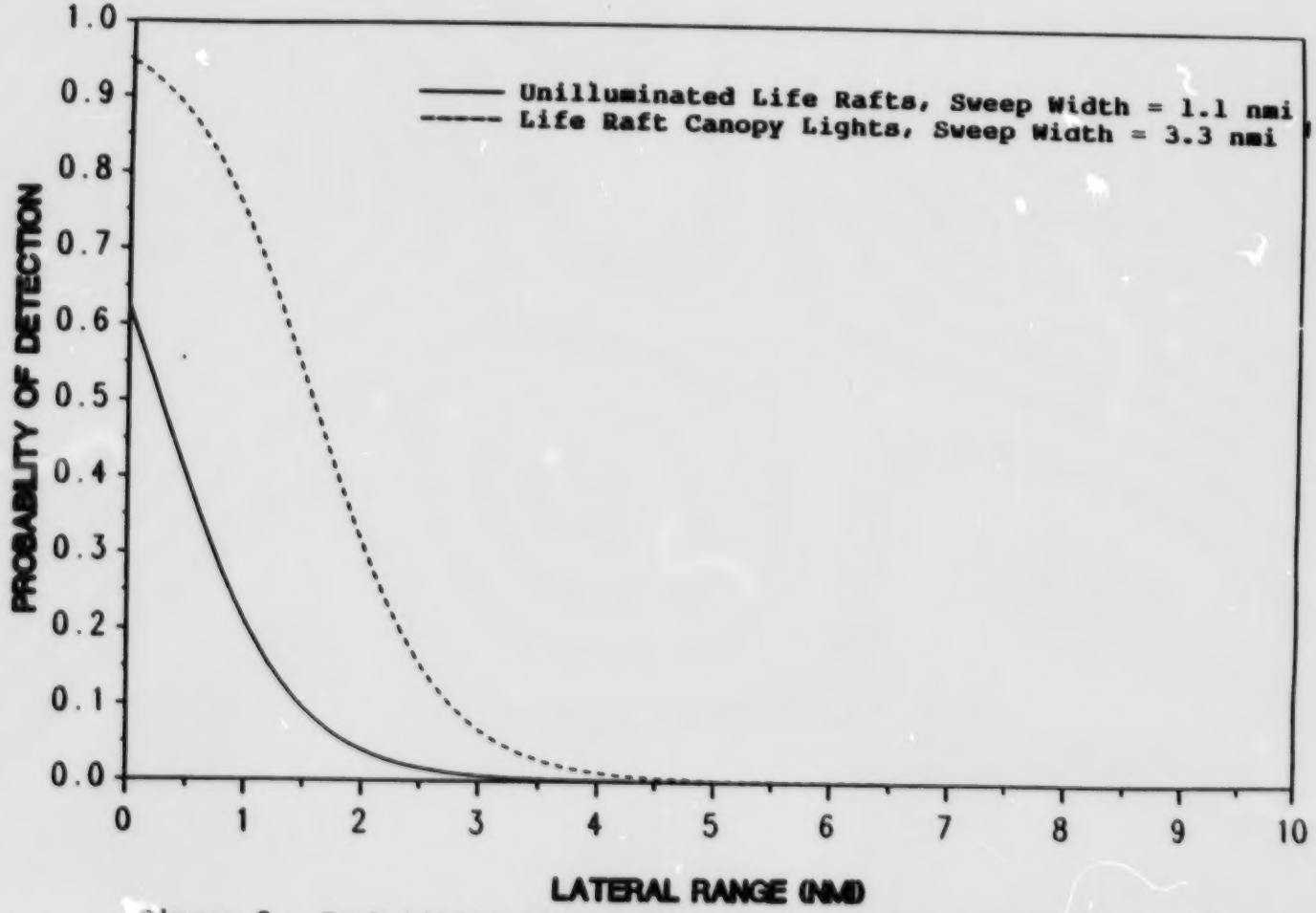

Figure 2 - Probability Of Detection Versus Lateral Range Derived From Night Vision Goggle Searches For Life Raft Canopy Lights And Unilluminated Life Rafts Using The CCGS "Sir William Alexander" (Lookouts On Monkey Island)

NORDCO LIMITED

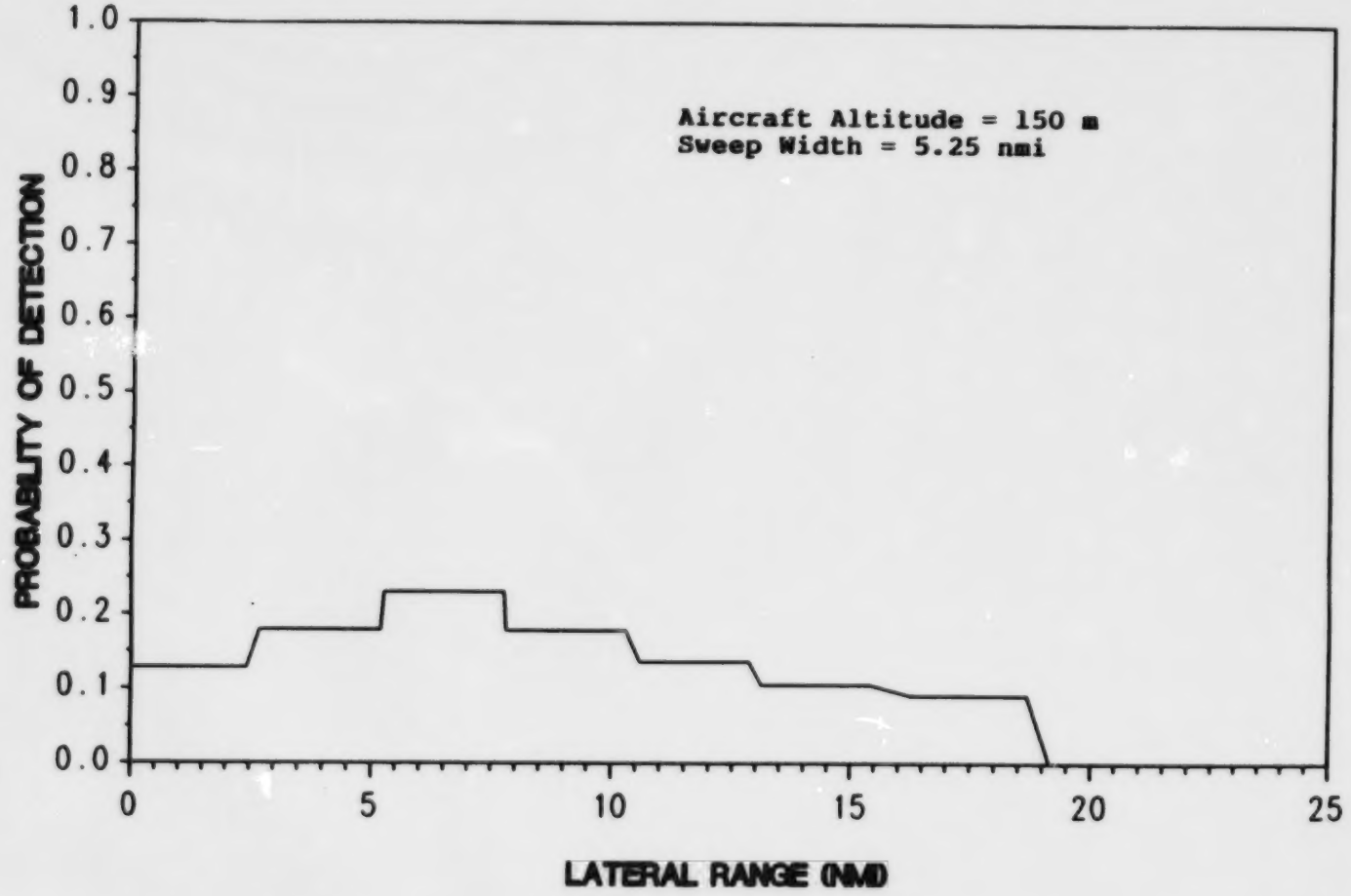

Figure 3 - Litton APS-504(V)5 Airborne Radar Probability Of Detection Versus Lateral Range Result For Four-And Six-Man Life Rafts With $2m^2$ Reflectors Mounted Inside

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5.6 Human Factors Observations

Appendix E contains a report by the human factors consultant, Dr. Paul Stager of York University. Those interested in this area are encouraged to read this appendix in order to obtain the full breadth of the human factors observations.

The observations and recommendations in Appendix E are based on a visit to the "Alert" on November 20 and 21, 1988 while it was in port, and on December 3 to 5, 1989 during simulated search operations. Dr. Stager inspected the bridge of the "Sir William Alexander" while that ship was in port on the evening of December 5, 1989. The major relevant observations were as follows:

1) There was no standardized visual scanning pattern used by the look-outs. It is not known whether the absence of a standard scanning pattern affected the visual detection performance.

2) The personnel employed may not have been a representative sample of potential lookouts from the point of view of experience, motivation, and visual capacity.

3) The bridges of both the "Alert" and the "Sir William Alexander" are poorly designed and equipped for sustained visual searches.

5.7 Discussion of Results

5.7.1 General

It is unfortunate that the 1988 work was plagued by vessel and other operational problems which limited the amount of simulated search time. This is turn has resulted in a very small ship based data set. The aircraft data set is about the size expected. The size of the ship data is of concern because it may not be a representative sample of the true performance. Any analysis of this data may thus result in erroneous conclusions. The following discussions are based on the assumption that the data set is a representative sample.

5.7.2 Daylight Visual Searches

In the 1987 SAR detection experiment, the significant independent variables for the daylight visual searches were lateral range, visibility, significant wave height, and raft type (six-man DND yellow canopied life rafts and four-man commercial orange canopied life rafts). DND life rafts were not used as targets in the 1988 experiment, though, four- and six-man commercial orange canopied life rafts were. In the 1988 experiment, life raft size was found not to be significant. On this basis, it may be concluded that the greater detectability of the DND liferafts in the 1987 work was probably due to their yellow colour and not their larger size.

Also, the analysis of the 1988 data showed that wind speed and not wave height (as was the case in 1987 experiment) was a significant factor. This is probably because of the predominantly higher wind conditions encountered in 1988 along with a less variable (although higher) range of sea states. These two variables are clearly interrelated and the level of significance of either depends on the range of conditions encountered during an experiment.

Table 4 compares the sweep widths for the three separate platforms (the "Sir William Alexander" 1988 data, collected with the lookouts on the monkey island, is considered to be a separate platform). The sweep width coefficients derived for each platform were used to predict the corresponding sweep width in the average relevant meteorological and oceanographic conditions encountered. This provides what is believed to be a valid method of comparison of the respective performance of each search platform. The average conditions for 1988 are taken from Table 1. The conditions for 1987 are given with Table 4.

At first glance, the results shown in Table 4 are certainly not what would be expected; however, the following points should be taken into account in assessing these results. Firstly, the crew of the "Alert" in 1988 was the same as that which participated in the 1987 experiment using the "Sir William Alexander". It is concluded that the improved performance in 1988 is a direct result of lookout experience and that this factor overwhelms the effect of slightly lower height-of-eye and the livelier motion characteristics of the "Alert". The statistical result that there is no significant difference between the "Sir William Alexander" (monkey island) performance and that of the "Alert" further reinforces this.

Secondly, the "Sir William Alexander" results should be assessed in the context that neither of the crews had participated in previous SAR detection experiments and, as a consequence, were "untrained". In the 1987 experiment the lookouts operated from inside the bridge while in the 1988 experiment the lookouts were stationed outside on the monkey island which has a height-of-eye about 3 m higher than that of the bridge. The increased height-of-eye and/or differences in other physical characteristics of the lookout locations (away from bridge, isolated, outside, etc.) would seem to be the cause for the improvement in performance, which was verified statistically as being significant.

5.7.3 Night Visual Searches for Life Raft Canopy Lights

In the 1987 experiment the "Sir William Alexander" attained a sweep width of 2.2 nmi for night visual searches against life raft canopy lights. The probability of detection was found to be a function of lateral range only. The negative result for the "Alert" in the 1988 experiment may be due to the small data set, or the vessel motion characteristics may be to blame. The two detections that did occur were at 0.1 and 0.25 nmi, respectively.

SEARCH PLATFORM	PREDICTED DAYLIGHT VISUAL SWEEP WIDTHS (NMI) FOR AVERAGE ENVIRONMENTAL CONDITIONS ENCOUNTERED BY EACH SEARCH PLATFORM		
	SIR WILLIAM ALEXANDER 1987 CONDITIONS [1]	SIR WILLIAM ALEXANDER (MONKEY ISLAND) 1988 CONDITIONS	ALERT 1988 CONDITIONS
Sir William Alexander 1987 (585/176) [2]	3.6	3.2	1.7
Sir William Alexander 1988 (Monkey Island) (32/13)	4.3	3.7	3.1
Alert, 1988 (72/23)	5.3	4.6	2.8

1 The average applicable conditions for 1987 were: 14 nmi of visibility, a wind speed of 20 knots, and a significant wave height of 1.5 m.

2 This is the total number opportunities/total number of detections.

Table 4 - Comparison Of Predicted Daylight Visual Sweep Widths For Average Environmental Conditions Encountered In 1987 And By The Two Ships In 1988

5.7.4 Night Vision Goggle Searches

In 1987, simulated night vision goggle searches against unilluminated four- and six-man life rafts were undertaken using the "Sir William Alexander" (lookouts on bridge). With a data set of 118 detections and opportunities the probability of detection was found to be a function of lateral range only and the corresponding sweep width had a value of 1.3 nmi. This compares reasonably well with the "Sir William Alexander" 1988 result (lookouts on monkey island) of 1.1 nmi (function of lateral range only) despite the very small sample size (15). Because of the small data set, little else can be said about the result. The "Alert" result against unilluminated targets may be another indication of the effect of ship's motion. The night vision goggles limited field of view of 40^{o}, combined with the type of target being detected and the vessel motion, probably all contributed to the relatively poor results obtained.

The night vision goggle sweep widths derived for illuminated targets, (life rafts with canopy lights activated), although again based on small data sets, seem to be reasonable. Although the data sets are too small for any valid statistical tests to determine whether the results are significantly different, the higher sweep width for the "Sir William Alexander" (monkey island) certainly agrees with what might be expected.

Operational problems in the use of these goggles were highlighted in the report on the 1987 experiment. Other problems, such as those associated with the requirement for open windows on the bridge, have been reported here (see Section 3.1 and Appendix E). However, another fundamental problem has also been identified with the use of the goggles. In a real search operation it is considered important that the vessel be visible to the occupants of the SAR target so that they can take positive action to alert the search vessel of their position. The requirement for the almost complete elimination of exterior radiated light on the search vessel when night vision goggles are in use clearly conflicts with this requirement. The use of illumination that is outside the sensitivity range of the goggles (minus blue lighting, for example) may help solve this problem.

5.7.5 Airborne Radar Searches

The Litton APS-504(V)5 radar search results are reasonable for this type of target. Had the radar been able to operate at its maximum antenna rotation rate its performance may have been significantly better. The high false detection rate is of considerable concern as frequent diversions from a search track to investigate each detection could substantially increase the time required to effectively cover a search area.

Neither of the USCG airborne radars had a confirmed detection. This is not unexpected for either radar in view of the prevailing conditions in the 1988 work. The SLAR was designed to enhance the return from the ocean surface, and the signal-to-clutter (sea) ratio due to sea conditions during the test period was probably prohibitive. The FLAR is a considerably less sophisticated search radar than the Litton radar, particularly in terms of the lack of pulse compression, and signal processing. This radar was also

flown at a non-optimum altitude for this type of target. The selection of the altitude was dependent on the SLAR, which was the primary radar being evaluated.

The Litton radar results demonstrate that even using a sophisticated radar equipped with substantial signal processing capability, search effectiveness is far from ideal for this type of target in the conditions encountered. There is clearly still a problem with the sea clutter in the near range. While target obscurity by ocean waves is shifted to a much longer range, the overall performance in the area outside the clutter zone is still very poor.

5.7.6 Transponder Detection

While the technical problems encountered prevented the derivation of any sweep width information, the ranges of detection encountered with the one operational unit were consistent with the 1987 experiment detection ranges. This would indicate that the sweep widths derived in the 1987 experiment are reasonably valid.

In the test conducted using the Litton APS-504(V)5 airborne search radar the transponder was clearly detectable at a range of 14.5 nmi. This was not the maximum range of detection and is good evidence of the potential benefit of the transponder. The requirement to operate the radar in a non-optimum mode in order to detect the transponder is cause for concern. In a real search operation using a single radar, the operator would have to switch frequently between two operational modes in order to search for passive targets as well as those equipped with transponders.

Finally, airborne search radars, unlike marine radars, tend to have system specifications that vary widely from radar to radar. Certain radars, because of their system characteristics (for example, vertically polarized antenna), are unable to detect the transponder signal. Clearly, if a search for such a transponder is undertaken using an airborne radar, it is essential that the radar is technically capable of detecting the return signal from the transponder.

5.7.7 Human Factors Observations

A detailed discussion of the observations made by Dr. Stager is given in Appendix E. The concern as to whether the personnel were a representative sample of potential lookouts does warrant some discussion here.

The search experiment methodology developed by the USCG requires that a SAR vessel and its crew be tested as an operational unit. The captain deploys personnel as he would normally do during a normal search. Which particular SAR unit (in a given vessel class) or crew is used is more dependent on vessel and crew availability at the time that an emergency occurs and not on a preferred selection process. The underlying assumption is that all SAR crews are approximately equal in performance. This assumption may be erroneous and the results from this experiment seem to indicate this is a possibility.

Another observation made by Dr. Stager was that there were a large number of variables involved in the detection experiments and isolation of these variables to determine their effect is desirable. The purpose of the multivariate regression analysis package is to isolate the effects of these variables; however, the inferred need for a large data set to accurately quantify their effect on a statistical basis, is quite valid.

Finally, it was reported that after a night vision goggle search on the "Alert", that the lookouts complained of puffiness and watering of the eyes. During the 1987 and 1988 experiments, this was the only time such a problem occurred. The crew was using the binocular units. It might be suggested that this was caused by faulty adjustment of the goggles or exposure to cold air. Later in the experiment, lookouts positioned outside on the monkey island on the "Sir William Alexander" used the monocular goggles and no such complaints were received. In the 1987 experiment, binocular units were also utilized without any complaints of this sort. Considering that it is doubtful 5 of 6 lookouts would have misadjusted their goggles and exposure to cold air in other searches did not cause problems, it seems likely that the motion characteristics of the "Alert" could have been the cau[illegible] due to the constant necessity to refocus the eye.

5.7.8 Other Issues

There were a number of other observations made that, while not directly pertinent to the project, are important in the context of search and rescue in that they relate to the adequacy of search and rescue equipment. These are discussed in the following paragraphs.

The life raft light batteries employed during the experiment lasted only about 8 to 10 h. These lights are water activated units designed to automatically activate when the life raft is deployed. The problem with this is that if a SAR incident occurs say in the morning, then the life raft light will be extinguished by night fall. Even if an incident occurs just before night fall, the searchers only have the above period of time to search effectively. Therefore, the utility of the present type of battery based lighting system is extremely limited.

Safety Of Life At Sea (SOLAS) regulations adopted in 1983 for all life rafts manufactured from 1986 onwards require the use of improved battery systems which last much longer. Battery units approved under the SOLAS regulation last almost 24 h and they can be turned on and off easily. However, the vast majority of life rafts still in use employ the old battery system and this is expected to be the case for a number of years. Thus, for some years to come, night visual and night vision goggle searches for lights will only be effective for very short periods (within the first 8 h or less of an incident) against most life rafts. Even under the new regulations, the lights may be operational only during the first 24 hr of an incident since survivors may not have the capability or even the knowledge to switch off the light in daylight hours.

The targets utilized in the experiment were a mixture of old (some decertified) and new commercial four- and six-man canopied lift rafts and 3 new DND six-man aircraft canopied life rafts. The commercial life rafts were manufactured either by Dunlop or Beaufort. The DND life rafts were manufactured by Tull and were NATO standard. Because of the mixture of commercial life rafts employed, it is impossible to make an observation regarding any differences in performance based on the manufacturer. However, there clearly was a difference between the DND life rafts and the commercial life rafts. While the DND rafts had substantially greater air retention, their canopies were destroyed under weather conditions (20 to 30 knot winds) in which the commercial life raft canopies survived.

In the latter stages of the experiments, icing started to become a problem. Often life rafts were retrieved with their canopies collapsed due to the weight of the ice. Once the ice was removed, the canopy returned to its proper state. These life rafts were moored and the canopies had become somewhat soft due to some loss of air. While it might be argued that this may be an unrealistic situation, it does indicate that icing might pose problems for rafts deployed in conditions where icing might be expected.

The report on human factors (Appendix E) addressed the question of ship design from the point of view of its effect on the performance of the lookouts. Those aspects of ship design which facilitate the transfer or retrieval of a SAR object onto the vessel are also very important. From observations made during the 1987 and 1988 experiments, it appears that in order for either the "Alert" or the "Sir William Alexander" to retrieve a life raft with people on board it would be necessary to deploy a small boat, such as a Fast Rescue Craft (FRC), as there appears to be no safe and effective way of bringing the raft directly on board the ship.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Visual Daylight Searches

Because of the small size of the data set, there is some concern regarding whether the results obtained are based on a representative sample. Assuming, however, that the visual sweep results arising from the 1988 work are accurate, two major conclusions can be formulated. First, because the crew of the "Alert" in 1988 was the same as the crew on the "Sir William Alexander" in 1987, it can be concluded that the improved performance in 1988 is a direct result of lookout experience and this factor overwhelms the effect of the slightly lower height-of-eye and livelier motion characteristics of the CCGS "Alert". It is noteworthy that one of the Maritime Region vessel captains independently stated it was clear to him that a "training" effect had to come into play. If the assumption is indeed correct, it can be concluded that a significant improvement in search capabilities would result if the CCG launched a lookout training program. Indeed, after the 1987 experiment, the subsequent detection of a life raft in a real SAR operation was attributed to the lookout experience.

The second conclusion that can be made follows from a comparison of the sweep width results attained by the "Sir William Alexander" in 1987 and in 1988. In these experiments, neither of the crews had participated in previous SAR detection programs and, as a consequence, were "untrained". In 1987, the lookouts operated from inside the wheelhouse, while in the 1988 work, the lookouts were stationed on the monkey island. Once again, assuming that the results are valid, it can be concluded that the greater sweep widths derived in 1988 are a direct result of the lookouts being on the monkey island. This resulted in an increase in sweep width from 0.5 to 1.4 nmi for the example environmental conditions tested. This is significant and provides the CCG with clear guidance for improving detection performance. There is evidence to suggest that placing lookouts on the ship's monkey island will improve their visual performance. However, again this is based on a very small data set which is an insufficient basis for recommending at present that the lookouts be placed on the monkey island during operational visual searches.

It is also concluded that for vessels comparable in size to the "Sir William Alexander" and the "Alert" operating in the range of environmental conditions encountered in the 1987 and 1988 experiments, there is no significant difference between the visual detectability of four- and six-man orange canopied life rafts. The increased detectability of the DND six-man yellow canopied life rafts over the four-man orange canopied life rafts is due to the colour of the DND life rafts. In the conditions encountered in the 1987 experiment, the resultant sweep width increase with the yellow life rafts was substantial and is predicted to range from 1.3 to 1.6 nmi in a wide variety of conditions.

In light of the preceding, the following specific recommendations are made:

1. While the results indicate that the "Alert" has a greater sweep width, the small size of the data set and the suggestion of a training effect make it difficult to recommend operational sweep widths based on them. Therefore, while it is indicated that the "Alert" has a better detection performance than the "Sir William Alexander", it is recommended that for the present the sweep width derived for the latter vessel in 1987 be used operationally for the "Alert".

2. It is recommended that a second detection experiment be carried out on the "Alert". The primary objectives of the experiment should be to augment the visual data set collected in 1988, to quantify the effect of training, and the effect of having lookouts on the monkey island. A human factors expert should be involved in all aspects of the experiments. It is important that the experiment take place while the ships's crew still includes the lookouts involved in the previous experiments.

3. If revised sweep width tables are to be derived for vessels of the same class as the "Sir William Alexander" and the "Alert", then the sweep widths for four-and six-man orange canopied life rafts should be considered equal. The sweep widths derived for the tables should be based on the results obtained in the 1987 experiment for the four-man orange canopied life rafts.

4. The CCG should initiate research into target colour and its effect on visual detectability, the ultimate goal of such research being to identify that colour which provides the maximum detectability in realistic visual search environments.

6.2 Night Visual Searches for Life Raft Canopy Lights

Due to the small data set, which was insufficient to allow a regression analysis, it is impossible to provide for the "Alert" any sweep width guidance for canopy lights. It is recommended that additional simulated searches of this type be undertaken to obtain sufficient data.

6.3 Night Vision Goggle Searches

For vessels of the "Sir William Alexander" and "Alert" classes, night vision goggles are effective against life raft canopy lights in the environmental conditions encountered. Because of the small data set, there is potential for a significant error in the sweep widths derived. Also, because of the small data set, it is not possible to draw any reliable conclusions regarding the difference between the two ships.

The night vision goggles are marginally effective against unilluminated life rafts when used on the bridge or the monkey island of vessels of the same class as the "Sir William Alexander " in the range of environmental

conditions encountered in the 1987 and 1988 experiments. The sweep width values derived are potentially subject to significant error because of the small data set size. A sweep width value for the "Alert" cannot be provided from the data collected, but it is expected to be considerably less than that obtained for the "Sir William Alexander".

The requirement for almost total absence of exterior lighting on the ship when using night vision goggles conflicts with the policy of making the ship as visible as possible when involved in an operational search. The necessity of opening windows on the bridge of a ship in order to use the goggles effectively can create an extremely uncomfortable operating environment on the bridge, and, under certain conditions can result in operational problems for the ship itself through the potential for equipment damage. This requirement also limits the scanning area available to the lookout, which in turn, limits the search effectiveness of the goggles.

The following recommendations are made regarding the use of night vision goggles.

1. Despite the small data set for life raft canopy light searches and the potential for error in the sweep width, the data from this experiment is the only information presently available on which sweep width guidance can be based for the CCGS "Sir William Alexander" and the "Alert" searching for standard life raft canopy lights at night using night vision goggles. In winds up to 20 knots, visibilities of 10 nmi or greater, significant wave heights of 1.8 m or less and no precipitation, a sweep width of 3.0 nmi should be used.

2. Again, as with the preceding recommendation, despite the uncertainty in the sweep width attained for unilluminated targets this is the only information presently available for search guidance. Therefore, for ships comparable to the "Sir William Alexander" using night vision goggles and searching for unilluminated life rafts in winds up to 32 knots, with visibilities of 10 nmi or greater, significant waves heights of 2.0 m or less, and no precipitation, a sweep width of 1.0 nmi should be used. No similar sweep width guidance can be given for the "Alert" at this time.

3. Night vision goggle searches should be conducted with the lookouts positioned on the monkey island.

4. The night vision goggle data set for both the "Sir William Alexander" and the "Alert" should be augmented through more detection experiments. The experiments should include tests to determine quantitatively the effect of having lookouts positioned on the monkey island as opposed to inside the bridge.

5. Before night vision goggle searches become a standard operational search technique, the CCG should investigate the conflicting requirements of maximum search vessel visibility and minimum exterior lighting. The investigation should include the importance of maximum visibility and exterior illumination options (minus blue lighting, for example).

6.4 Airborne Radar

The Litton APS-504(V)5 radar deployed on the Atlantic Airways Limited Beech King Air aircraft is effective in searching for four-and six-man life rafts under the environmental conditions encountered. The high rate of false detection is cause for concern as operationally it will result in frequent diversions from a search pattern, substantially increasing the time to cover a search area. The Motorola AN/APS-131 SLAR and the Texas Instruments AN/APS-127 FLAR installed on the USCG aircraft jet and tested in this experiment are not effective at the altitudes flown for life raft targets under the environmental conditions encountered.

The following recommendations are made:

1. If this particular Atlantic Airways radar/aircraft configuration is to be used in operational searches for four-and six-man life rafts, then in winds up to 34 knots and significant wave heights of 3.0 metres or less a sweep width of 5.0 nmi should be used. The aircraft altitude should be maintained at 150 m during the search.

2. If the radar configuration is modified to allow operation utilizing an antenna rotation of 120 r/min and it is to be used for SAR, then a second detection experiment should be undertaken to determine the new sweep width.

3. Any future evaluations of this radar should include the false detection aspect.

6.5 Radar Transponders

While no marine radar detection data were collected to derive sweep widths, the few detection observations made were comparable with those made in the 1987 experiment. It is concluded that the sweep widths derived in that experiment are reasonable and can be used for search guidance.

The airborne radar detection test indicated the important potential of the radar transponder, however, the transponder used will only be an effective target for certain radars and only when these radars are operated in a particular mode. Clearly, considerable investigative work regarding the specifications of a SAR transponder is required prior to development of a standard unit.

In view of the foregoing, the following recommendations are made:

1. If the CCG is considering sponsoring the development of a radar transponder considerable investigative work regarding the specifications

of such a unit is necessary to ensure compatibility with the marine and airborne radars that will likely be used in a search operation.

2. If any further SAR detection experiments are undertaken, an attempt should be made to integrate transponder detection tests into the experiments.

6.6 Human Factors

The human factor's observations provided valuable insight into the human aspects of a search operation which pertain to lookout performance. The report (Appendix E) provides direction for improving the detection performance and indicates areas where further research is required. The reader is encouraged to refer to Appendix E for a detailed discussion of the recommendations. The summary recommendations are as follows:

1. Undertake a research project to develop an optimal visual scan pattern for the marine environment that takes into account known limitations in human visual search capabilities.

2. Develop an effective training program in visual search methods and a means for periodic performance evaluation of CCG personnel involved in visual searches.

3. Undertake an experimental program to investigate the effect of contrast sensitivity on probability of detection values associated with marine searches.

4. Undertake a limited research program to determine the maximum search time, including active lookout time on station, that can be expected of lookouts without degrading probability of detection performance.

5. Undertake a program to modify existing workstations for lookouts using known human factors standards.

6. Continue to investigate the use of night vision goggles for searches.

7. Prepare a standard operating manual for visual search procedures and ensure adherence to the recommended procedures.

One other recommendation not specifically made by Dr. Stager but made here as a result of his observations is:

8. Lookouts should stand watch for a maximum of 1.0 h. The 2.0 h watch period is too long and until such time as an optimum period is identified, the 1.0 h period would seem to be a reasonable compromise. This watch period should apply to both visual and night vision goggle searches.

6.7 Other Issues

6.7.1 Life Rafts

The DND life raft canopies are not as structurally sound as those of the commercially available life rafts tested in this experiment. Because the method of deployment (attachment to a mooring) is unrealistic, it is unknown whether these canopies would withstand a normal deployment situation and thus meet the required specifications.

There is evidence to suggest that icing may cause commercial life raft canopies to collapse. This will reduce the detectability of the life raft and create problems for incapacitated survivors in the life raft.

While the results show that SAR vessels can effectively search for life raft canopy lights at night either visually or with night vision goggles, the relatively short operational life of the batteries severely limits the effective search time. While occupants of a life raft can turn off such lights to conserve battery power, it must be assumed that in the majority of cases they are incapable of doing this.

In view of the foregoing, the following recommendations are made:

1. DND should be made aware of the observations made concerning the structural integrity of the NATO standard six-man yellow canopied life rafts, so that an investigation can be undertaken, and, if necessary, design changes can be instituted.

2. The CCG should investigate the canopy icing problem to determine its significance.

3. Under the new SOLAS regulations adopted by Canada in 1986, life raft canopy light systems in all life rafts are to provide about 24 h of illumination. This is felt to be insufficient to provide enough night search capability. It is recommended that, if possible, the effective life be increased to at least 48 h.

6.7.2 SAR Vessel Retrieval Capability

Ships similar to the "Alert" and the "Sir William Alexander" are not well designed for the recovery of life rafts, particularly in rough seas and when the life raft occupants may be incapacitated. The requirement to put a small recovery craft into the water in conditions which may put more people at substantial risk is certainly not a satisfactory situation. It is, therefore, recommended that the CCG initiate the investigation of methods and/or systems for the effective and safe retrieval of life rafts by SAR vessels. Designs of proposed new SAR vessels should be re-evaluated in light of this problem as well.

6.7.3 Search Equipment

SAR experiments to date have primarily involved the detection of targets from surface vessels. The experiments are costly and involve a substantial number of personnel and a considerable amount of equipment. It would seem wise to maximize the benefits from such an experiment. Airborne visual and electronic detection experiments could easily be conducted simultaneously with surface searches as was demonstrated in the last experiment. It is understood that DND conducts the vast majority of any airborne searches and these experiments would provide an excellent opportunity to evaluate their airborne search capability and provide training. This would maximize the potential benefit from the overall experiment. It is, therefore, recommended that DND be invited to actively participate in any future relevant experiments. This invitation should be extended in the early planning phases of such experiments to allow sufficient time for that department to decide upon and make arrangements for participation.

6.7.4 Data Collection, Reduction and Analysis Issues

The results of the experiments that have been undertaken have importance both nationally and internationally. The costs of such experiments are also extremely high. Therefore, it is important that any future experiments be conducted in a cost effective manner and to acceptable standards. In the past, NORDCO has attempted to achieve this by working closely with USCG and CCG staff and utilizing various techniques to minimize the cost of data collection. There has, however, been only limited technical involvement by the CCG. The navigation package is a good example of a cost saving technique in that the package developed is cheap and reliable in comparison to complete navigation systems often employed by the offshore survey industry. Computer based data reduction and analysis packages have also been developed to maximize efficiency. Unfortunately, these packages and the navigation package have little or no documentation and are not very user friendly, having been used to solve the problem at hand by technical staff. In the interest of ensuring that future experiments are conducted to acceptable standards and in a cost effective manner, the following recommendations are made:

1. The CCG should establish a technical research group whose mandate is to actively participate in all aspects of SAR related contracts and work side-by-side with contractors to ensure the work is performed to acceptable standards. This will ensure that the CCG has an in-house group of expertise able to effectively monitor and assess all the future research work.

2. The navigation data reduction and data analysis packages (multivariate regression analysis package) should be developed into fully documented user friendly software products and delivered to the CCG. Staff within the CCG should be trained in the use of all the packages.

3. A detailed experiment procedure manual should be developed which provides step-by-step procedures for all aspects of a SAR detection experiments including data reduction and analysis. The USCG should be involved in the development of the manual.

6.8 Summation

Despite the technical problems which severely limited the data collection on the "Alert", considerable knowledge was gained from this experiment. As a result, search guidance has been provided for daylight, night visual and night vision goggle searches. The most important findings are the indication that training has a significant effect on lookout performance and that positioning lookouts on the monkey island significantly increases their detection performance. Because of the major implications of these findings, it is considered imperative that a second SAR detection experiment be conducted to augment the data set for the "Alert". The experiment should be designed to verify these findings and it is important that the effect of using "trained" and "untrained" lookouts be investigated.

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Cox, D.R., 1970. The Analysis of Binary Data. Methuen and Co. Limited, London.

Dawe, B.R., D. Finlayson and D. Bryant, 1988. Search and Rescue Detection Experiment - Canso Bank, 1987. Transport Canada Report No. TP9475E.

Koopman, B.O., 1980. Search and Screening, General Principles With Historical Applications. Pergamon Press, New York, 369 pp.

Appendix A

DETAILED EXPERIMENT PLAN

SEARCH AND RESCUE DETECTION EXPERIMENT
CANSO BANK, AUTUMN 1988
DETAILED EXPERIMENT PLAN

October, 1988

BY
B.R. DAWE
D. FINLAYSON
J. RUSSEL

NORDCO Limited File Ref.: 210-88G

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1. INTRODUCTION

This document constitutes the experiment plan for a ship and aircraft search and rescue (SAR) visual and radar detection project. The experiment will use the conventional methodology for deriving sweep width data to be used in SAR mission planning. The experiment involves mooring a number of four- and six-man life rafts as search objects in a pre-arranged array and operating a Canadian Coast Guard (CCG) SAR vessel in standard search patterns through the array while visual and radar detections are recorded. In this experiment, the Canadian Coast Guard Ship (CCGS) "Alert" will be the designated SAR vessel. The CCGS "Sir William Alexander" is designated as the support vessel to deploy and retrieve moorings.

There are 4 main objectives for the experiment. One is to obtain visual sweep width data under typical Canadian sea conditions (sea states 3 and higher). The second is to obtain sweep width data using night vision goggles (The night vision searches will be done between November 10-25 to take advantage of the moonlight during that period). The third objective is to obtain sweep width data for marine radar used in searches for X-band radar transponders. The fourth objective is to obtain information on the detection of SAR objects by Side-Looking Airborne Radar (SLAR) and search radar systems.

The experiment is to take place over the approximate period of November 7 to December 14, 1988. The location will be the Canso Bank on the Scotian Shelf off Nova Scotia. At times, a full 24 hour operation can be anticipated.

The following sections contain the detailed schedule, information on the experiment location, a description of the navigation system to be used, and details on other equipment to be used in the experiment. A brief description of the experiment methodology is included along with a discussion of manpower requirements.

2. SCHEDULING

The planned schedule is as follows:

Nov. 1-4 Mobilization of equipment in St. John's and loading of the rental truck.

Nov. 5 J. Lundy and R. Tucker depart St. John's for Dartmouth, N.S. by truck.

Nov. 6 (evening) Lundy and Tucker arrive in Dartmouth to join the "Alert". A. Pagan flies from St. John's to Halifax to join the assigned buoy tending vessel, the "Sir William Alexander", at the CCG Base in Dartmouth.

Nov. 7 Mobilization of the "Alert" begins. Twenty life raft mooring assemblies prepared at the CCG Dartmouth Base and life rafts loaded aboard the buoy tender. Wave measuring buoy, receiver and computer, and railway wheel anchors from Seastar Instruments Ltd. loaded on board the buoy tender.

Nov. 8 The buoy tender departs for Canso Bank. The LORAN-C buoys, LORAN-C moorings, and wave measuring buoy moorings, and additional life rafts trucked from St. John's loaded on board the buoy tender. Mobilization of the CCGS "Alert" continues in Mulgrave.

Nov. 9 The buoy tender arrives in the experiment area at first light and begins deploying the LORAN-C and wave measuring buoys, followed by the life raft moorings. J. Russell, D. Finlayson, and K. Elliott together with W. Reynolds of the United States Coast Guard (USCG) fly to Halifax and travel by rental car to Mulgrave to join the "Alert".

Nov. 10 R. Tucker drives the rental truck to Halifax and returns to St. John's by air. Mobilization of the "Alert" completed. Buoy tender continues deploying life raft moorings.

Nov. 11 "Alert" arrives at nearest target mooring to coast at first light and begin fixing target positions. The buoy tender will attach life rafts to the moorings which have had positions fixed. "Alert" will carry out a night vision search for illuminated targets.

Nov. 12 "Alert" used to fix positions of remaining moorings followed by a night search for illuminated targets deployed by the buoy tender.

Nov. 13 Begin daylight visual and radar searches.

Nov. 14 Daylight, night visual, and radar searches continue.

Nov. 15 Searches continue. R. Fitzgerald flies from St. John's to Halifax then travels by rental car to Mulgrave.

Nov. 16 "Alert" arrives in Mulgrave for ship's crew change. USCG representative disembarks to return home. R. Fitzgerald joins the vessel which then returns to the experiment area. Night visual search conducted overnight.

Nov. 17 Radar, daylight, and night visual searches continue. B. Dawe and J. Ryan travel from St. John's to Halifax.

Nov. 18 Airborne radar detection searches begin. B. Dawe and J. Ryan direct and monitor airborne searches by Atlantic Airways and liase with USCG regarding aircraft searches. Buoy tending vessel used to redeploy life raft targets throughout the mooring array, then remains at the LORAN-C mooring location during each airborne search. Surface searches continue.

Nov. 19-20 Airborne and surface searches continue.

Nov. 21 Airborne searches continue. "Alert" interrupted from surface searches to return R. Fitzgerald to Mulgrave and pick up Dr. Paul Stager of York University. Fitzgerald returns to Halifax by rental car and then flies to St. John's. Vessel returns to the Canso Bank.

Nov. 22-24 Airborne and surface searches continue. Life raft targets serviced and redeployed by the buoy tending vessel. Final air searches on Nov. 24.

Nov. 25 "Alert" returns to Dartmouth. NORDCO personnel, J. Russell, D. Finlayson, J. Lundy, and K. Elliot return by air to St. John's. P. Stager returns to Toronto. The buoy tender retrieves SAR targets and LORAN-C buoy on the Canso Bank. Upon completion the vessel travels to Mulgrave. A. Fagan travels by surface to Halifax then flies to St. John's.

Nov. 26-30 The buoy tender to monitor moorings if in experiment area.

Dec. 1 (evening) NORDCO personnel R Fitzgerald, J. Russell, K. McCarthy, R. Tucker, and A. Fagan fly to Halifax and join the "Alert" at the CCG Base, Dartmouth. The "Alert" then departs for Mulgrave.

Dec. 2 "Alert" arrives in Mulgrave. A. Fagan transfers to the buoy tender which proceeds to the experiment area and commences deploying the LORAN-C buoy and SAR targets. "Alert" begins visual and radar searches.

Dec. 3-13 Visual and radar searches continue. The buoy tending vessel services and redeploys moorings as necessary whenever available.

Dec. 14 "Alert" arrives in Mulgrave. The buoy tender retrieves targets and proceeds to Mulgrave. All gear from the "Alert" transferred to the buoy tender. The buoy tender returns to the experiment area to continue retrieving moorings. A. Fagan and R. Tucker remain on the buoy tender to complete demobilization.

Dec. 15 R. Fitzgerald, J. Russell, and K. McCarthy travel by rental car to Halifax then return to St. John's by air.

Dec. 16 Mooring retrieval continues using the buoy tending vessel then proceeds to Dartmouth.

Dec. 17 Buoy tender arrives at the CCG Base in Dartmouth. Demobilization begins.

Dec. 18 Demobilization completed.

Dec. 19-20 A. Fagan and R. Tucker drive rental truck containing equipment back to St. John's.

This schedule is subject to change due to weather, equipment problems, or the ship being called out on SAR missions. It is therefore meant only to be a guide. The LORAN-C buoy may require maintenance on more than one occasion. The life rafts will have to be serviced frequently to ensure that they remain fully inflated, and to replace batteries.

Decisions on removal of the life rafts temporarily will depend on forecast weather conditions, especially if the ship is departing the area for port. Relocation of the SAR targets throughout an array of moorings is required to avoid data biases due to the CCG observers "learning" the location of the targets.

3. EXPERIMENT LOCATION

The experiment will take place on the Canso Bank off Nova Scotia as shown in Figure 1. It was selected for the following reasons:

1. It is within an area of operation of the vessel CCGS "Alert" to be used in the experiment.
2. It is an area in which there are expected to be a minimal number of SAR incidents during the period of the experiment.
3. The area is an exposed offshore area where sea states of 3 to 5 can be expected.
4. It is close to the CCG base at Mulgrave, N.S.
5. The water depths will minimize mooring costs and operating difficulties.
6. The area is not a high traffic zone and this minimizes the possibility of interference with the experiment.
7. The area has excellent LORAN-C coverage.

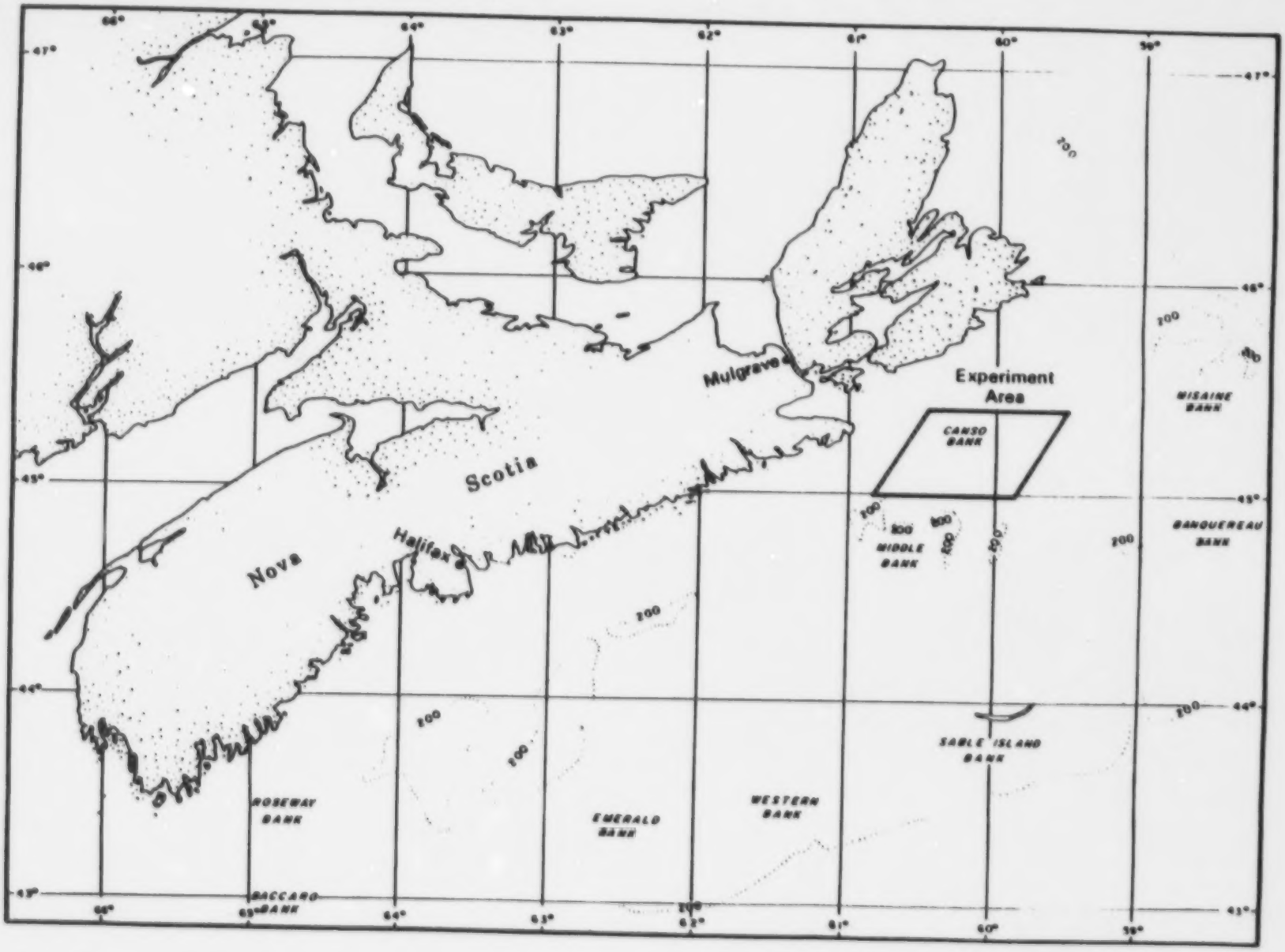


Figure 1 Location of Experiment

4. PARTICIPANTS

NORDCO Limited personnel will be conducting the experiment. Normally, the primary crew will consist of 4 individuals, two trained meteorological observers, a computer scientist, and an electronics technician. There will be one United States Coast Guard (USCG) representative on board from Nov. 9 to Nov. 16, 1988.

There will be a human factors expert from Ergo Systems Limited aboard from Nov. 21 to Nov. 25. It is expected that there will be a maximum number of 6 persons in the scientific party at any time during the experiment.

Atlantic Airways Limited will participate in airborne radar searches between Nov. 18 and 24. Atlantic Airways personnel will be operating their Litton APS-504(V)5 search radar during these trials. The USCG will also carry out airborne searches using an aircraft equipped with a SLAR and a forward looking radar. The exact time frame for the USCG search is yet to be determined.

It is understood that, from time to time, there may also be additional CCG personnel on board the vessel. Two additional CCG officers will be required as radar operators during the experiment. The ship's crew will be required as lookouts during visual searches.

A 24 hour operation is planned with two NORDCO Limited employees on each 12 hour watch. One person, the field manager will normally work days only, but will be on 24 hour call. The regular search personnel will log visual detection data and meteorological/oceanographic data as well as monitor the navigation and wave measuring buoy systems. The CCG radar operators will log their own detections. The technician and the computer scientist will be responsible for handling any equipment and software problems that may arise.

It is planned to conduct searches on a 24-hour basis whenever possible. Searches will be undertaken at night in order to obtain visual sweep width information for life rafts equipped with lights and to investigate the performance of night vision goggles.

5. EQUIPMENT

5.1 General Description

The equipment to be installed on the SAR research vessel or deployed on the Canso Bank includes:

1. a Datawell wave measuring buoy with receiver, processor, display, and recording system;
2. a navigation system utilizing an Internav LC-360 LORAN-C receiver;
3. Fifteen four- and six-man canopied life rafts (10 of which will be deployed at any given time);
4. twenty moorings for the life rafts; and,
5. Ten LENSREF radar reflectors.

5.2 Moorings

Moorings will be required for the life rafts, the wave measuring buoy, and the LORAN-C buoys. Each must satisfy specific requirements.

The life raft mooring arrangement is shown in Figure 2. The mooring is a single point configuration to allow for easy and efficient placement and retrieval. This will allow the moorings to be moved during the experiment. The life raft attachment will enable personnel to secure and release the life rafts easily so that maintenance can be undertaken.

Figure 3 shows the wave measuring buoy mooring arrangement. This is a standard mooring for this instrument.

Figure 4 shows the mooring arrangement for the LORAN-C buoy. As the buoy is designed for use in a free drifting mode, this mooring is designed to minimize the forces on the buoy during rough seas. The taut mooring arrangement will minimize horizontal excursion of the buoy, enabling the LORAN-C time differences to provide differential corrections for the navigation system.

5.3 Radar Reflectors

Lensref Luneberg lens type radar reflectors will be suspended inside 10 of the life rafts to enhance their radar reflectivity for the airborne radar searches. The 20 centimetre diameter Lensref reflectors (Model DL-8A) have a radar cross section of 2 square metres. Their reflectivity is omnidirectional in the horizontal plane.

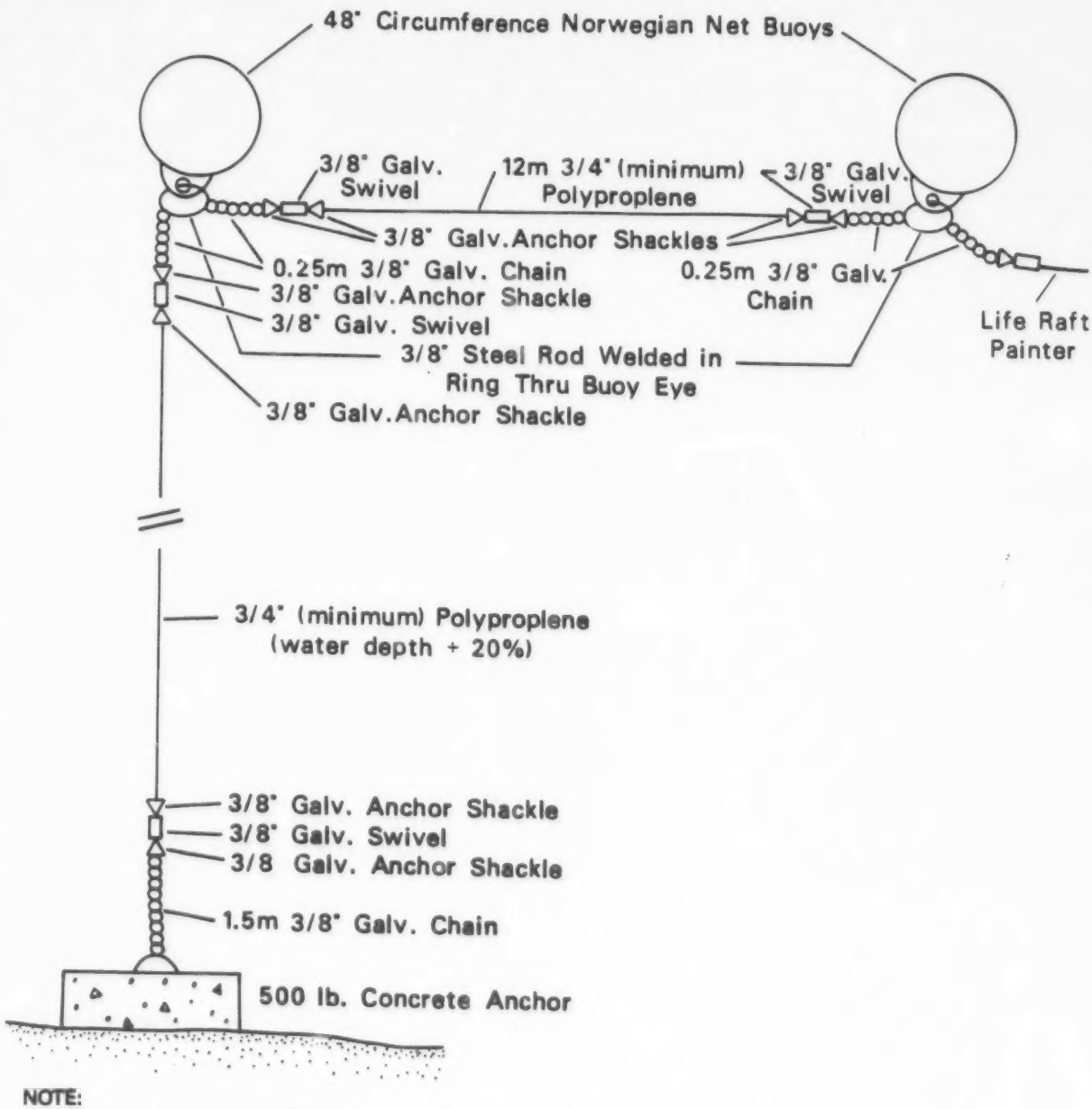
5.4 Navigation System

A differential LORAN-C hyperbolic radio positioning system will be used to determine the positions of the targets and the track of the vessel. Based on previous experience on the Canso Bank, the radial error (relative) accuracy is expected to be better than 95 metres (2 drms value).

Figure 5 illustrates the navigation system configuration. One LORAN-C buoy, moored in the centre of the experiment area, will monitor the time difference (TD) from each of the 3 master/secondary pairs on the Canadian East Coast chain (5930X, 5930Y, 5930Z). A taut mooring system will be used to reduce the horizontal excursion of the buoy. Ten minute (min) average time differences will be transmitted by VHF link to the ship at 10 min intervals. The TD data will be passed from the VHF receiver to a Compaq Portable II microcomputer system. The difference between the received TD's at the buoy and the long term mean TD's from that position will be used as the diffential (delta ASF) correction. The averaged TD data from the buoy will be filtered using an alpha recursive filter; filter weighting will be manully adjustable depending on the variability of the TD data.

The time differences for all 5930 master/secondary pairs will be monitored on board the ship using an Internav LC 360 LORAN-C receiver. This receiver will pass TD's via an RS232 interface port to the Compaq computer every 24 seconds. These data will be, corrected for cycle jumps, filtered using an alpha resursive filter, then adjusted using ASF and delta ASF corrections. A latitude-longitude fix will be computed for each available TD pair using an algorithm developed by Shudde (1984). When 3 TD's are available, a most probable position (MPP) will be computed from the resulting 3 latitude-longitude fixes based on the variability of the differences between the observed and filtered TD data. In the event that only 2 TD's are available, the computed fix will be considered to be the most probable position. A plotting routine will update a screen display of the ship's position and track each time a new MPP is computed.

Raw TD data from the LORAN-C buoy and the ship based LC 360 receiver will be archived to a disk file on the Compaq computer each time data are received. In addition, the computed MPP will be logged as well. A hard copy printout of certain raw and processed data will be made once each minute during periods when searches are being conducted.


48" Circumference Norwegian Net Buoys
3/8" Galv. Swivel
12m 3/4" (minimum) Polypropiene
3/8" Galv. Swivel
3/8" Galv.Anchor Shackles
0.25m 3/8" Galv. Chain
3/8" Galv.Anchor Shackle
3/8" Galv. Swivel
3/8" Steel Rod Welded in Ring Thru Buoy Eye
3/8" Galv.Anchor Shackle
0.25m 3/8" Galv. Chain
Life Raft Painter
3/4" (minimum) Polypropiene (water depth + 20%)
3/8" Galv. Anchor Shackle
3/8" Galv. Swivel
3/8 Galv. Anchor Shackle
1.5m 3/8" Galv. Chain
500 lb. Concrete Anchor

NOTE:

- all polypropiene sections terminated in 3/4" nylon thimbles
- all shackles secured by nylon cable ties
- Galv - galvanized

FIGURE 2 Liferaft mooring arrangement

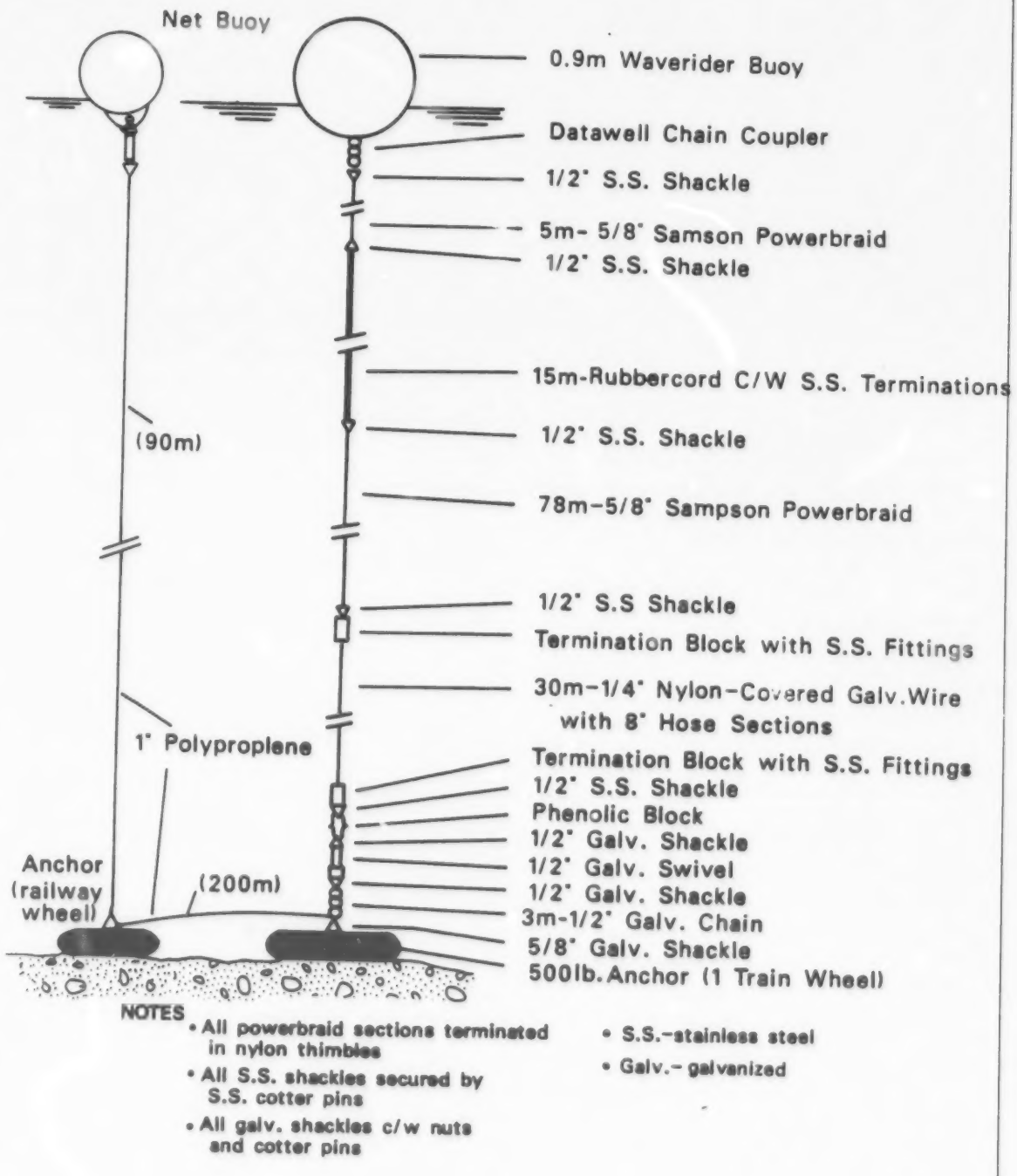
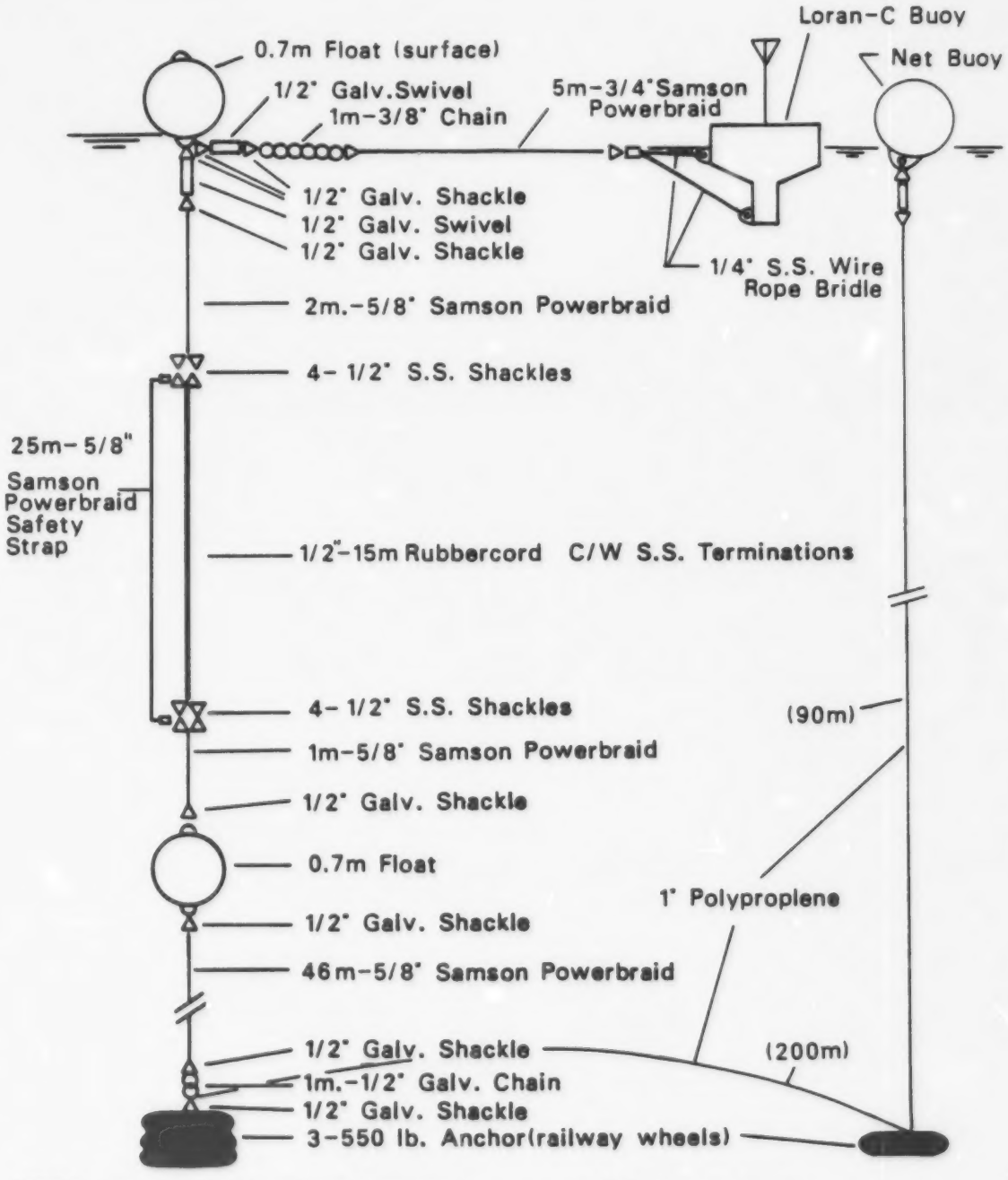
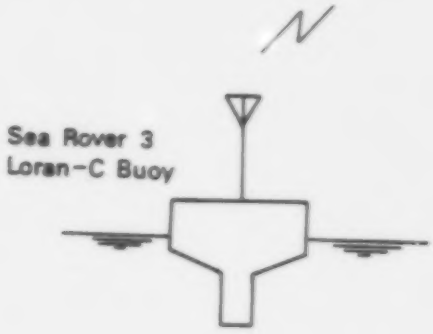


FIGURE 3 Wave measuring buoy mooring arrangement



NOTES:
- All powerbraid sections terminated in nylon thimbles
- All S.S shackles secured by S.S. cotter pins
- All galv. shackles c/w nuts and cotter pins
- S.S.-stainless steel
- Galv.-galvanized

FIGURE 4 LORAN-C buoy mooring arrangement



SHIPBOARD NAVIGATION SYSTEM

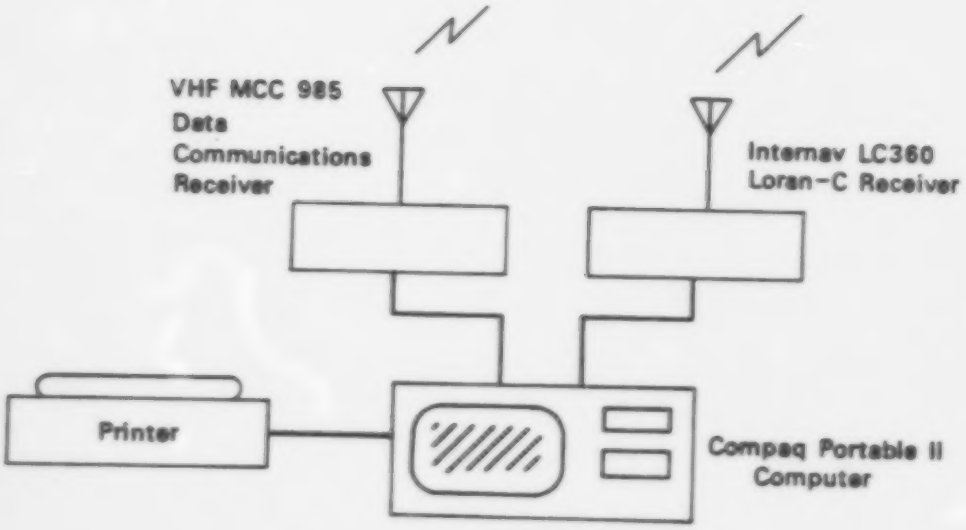


FIGURE 5 Navigation system configuration

6. EXPERIMENT METHODOLOGY

Upon deployment of all the targets, an experiment search pattern will be planned by NORDCO Limited personnel. Prior to starting the search all information regarding search target locations will be removed from the bridge.

Visual searches will be undertaken during daylight hours. At night, a visual search will be undertaken to look for the lights on the life rafts. Night vision goggle systems will be used at times. The ship's officers will operate as they normally would during a search operation. When a target is detected by a lookout, he will report the approximate range and bearing (relative to ship's heading) to the NORDCO observer on watch and proceed to look for other targets. The NORDCO observer will log the detection information and other ancillary data.

A radar search for radar transponders will be carried out simultaneously with the visual searches at times. Radar operators will be provided with log sheets on which to report their detection data and radar setting parameters. Operators will be required to monitor the radar display for varying amounts of time. This time will either be 1, 2, or 3 hours. The monitoring time during each search will be designated by NORDCO personnel.

NORDCO observers will record all the appropriate weather and sea state information every hour or whenever conditions change significantly. The wave measuring buoy output will also be logged hourly.

Appendix A1 contains copies of the visual, radar, and environmental log sheets to be used during the experiment.

The navigation system, placed on board the ship for the experiment, will automatically log and display the ship's position. For experimental reasons its display will not be available to the ship's officers. NORDCO observers will, however, check its operation periodically, as knowing the position of the ship in relation to the search objects at any given time throughout the search will be crucial to the data analysis.

The actual length of time for any given search operation will depend on a number of factors, including weather and sea conditions, target maintenance requirements, and crew fatigue. The decision will be left to the senior NORDCO representative on board and the ship's captain.

Airborne radar searches will be carried out by Atlantic Airways using a search radar. The USCG will also take part in searches using an aircraft equipped with a SLAR and a forward looking radar. For the detailed methodology on the airborne component of the work see Appendix A2.

REFERENCE

Shudde, R.M., 1984. A Non-iterative Algorithm for Loran-C Position Determination. Navigation: Journal of the Institute of Navigation, Vol. 31, No. 3, pp. 179-198.

APPENDIX A1

Data Logging Sheets

VESSEL _____

ENVIRONMENTAL DATA LOG SHEET

DATE _____ DAY _____ YEAR _____

TIME GMT	POSITION Lat. °	Long. °	SKY CONDITION	WIND kts	SEA ft	CLOUDS	TEMPERATURE Dry °C	Wet °C	BP °C	SEA ft	SWELL Height ft	Speed kts	APPARENT WIND Knots	Speed kts	TRUE WIND Knots	Speed kts

VISUAL SIGHTING REPORT FORM

Search Number _____ Month _____ Day _____

Start Time _____ End Time _____ Year _____

Sighting No.	Sighting / Turn Time	Range (nm)	Relative Bearing (deg)	Bearing of Sun (deg)	Heading (deg T)	Lookout/ Position	Remarks	Obsr.

NORDCO LIMITED

APPENDIX A2

SAR '88

Airborne Technical Plan

SAR '88

AIRBORNE TECHNICAL PLAN

OCTOBER, 1989

Sigma Engineering Limited
St. John's, Newfoundland

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APPENDIX A2-1 - Litton APS-504(V)5
APPENDIX A2-2 - AN/APS-131 SLAR
APPENDIX A2-3 - AN/APS-127 FLAR
APPENDIX A2-4 - Log Sheets

1. INTRODUCTION

During November 1988 Nordco Limited will conduct an experiment to investigate the effect of platform and environmental parameters on the sweep widths applicable to shipboard visual and radar searches for life rafts. The exercises will be conducted on the Canso Bank off Nova Scotia using the Canadian Coast Guard Ship "Alert". The experiment will use established United States Coast Guard (USCG) methodology to collect target detection data for in use in deriving sweep widths for visual and radar searches. In conjunction with this shipboard experiment an airborne detection experiment will be carried out using a Search Radar, A Litton APS-504(V)5, a Side-Looking Airborne Radar (SLAR) and a Forward-Looking Airborne Radar (FLAR). The Search Radar will be contracted by Nordco Limited from Atlantic Airways Ltd. of St. John's and the SLAR and FLAR will be operated by the USCG. The airborne experiment will provide the opportunity to compare the performance of an advanced Search Radar with that of the SLAR and a conventional FLAR. The FLAR has specifications similar to the radars in the Canadian Tracker aircraft used for fisheries patrol.

The major objective of the airborne component of SAR '88 will be to acquire the first set of data on the performance of the Litton radar for life raft detection. This data will be used to derive sweep widths for comparison with other airborne (SLAR and FLAR) and shipboard radar sweep widths. The data collected on the Litton radar will form the basis for data to be collected on future airborne SAR exercises such as that planned for LIMEX'89. In addition the experiment will increase the sweep width data base for the USCG SLAR and FLAR to include data from higher sea states.

The airborne searches will be conducted during the second week of the ship based exercises over the period November 18 to 23, 1988.

The following technical plan provides the experiment methodology and details of the logistics.

2. SCHEDULE

The airborne searches using the Litton radar onboard a Beechcraft King Air B200 will commence on November 18 and continue for five days. During the experiment the King Air will be based at Halifax International Airport. One search will be conducted daily using the Litton radar. It is expected that the USCG Falcon with SLAR and FLAR radars will be available for several days during this period and the Litton radar flying schedule will be arranged to accommodate the schedule of the Falcon. The Falcon will fly out of Cape Cod, Massachusetts and it will typically be expected on site by late-morning (10:30 to 11:00 AM Local Time). This would permit an early morning flight by the King Air and would ensure that both aircraft are not in the search area at the same time. Depending on the length of the search pattern selected it is expected that both the Falcon and the King Air will spend two to three hours of active searching on each flight. On a day when both aircraft are available the tentative flying schedule will be as follows;

Flight 1 King Air: Wheels off Halifax International at 6:00 AM Local Time. Arrive at test area by 7:00 AM and conduct search pattern. Return to Halifax. Arrive at Halifax at 11:00 Noon.

Flight 2 Falcon: Arrive at test site at 10:30 Local and conduct search pattern. Complete search pattern by 1:00 PM. Proceed to CFB Shearwater for fuel.

Flight 3 Falcon: Wheels off Shearwater at 3:00 PM. Run final search patterns and return to Sherwater for fuel. Return to Cape Cod.

The schedule may be tightened up once flying and turn around times are confirmed. Depending on the arrival time of the Falcon for its first flight it may be more appropriate to schedule the King Air search between searches by the Falcon. It is expected that considerable flexibility will be required in setting the daily schedule as unforeseen equipment failures and weather may effect the operation of both the aircraft and the search vessel.

3. AIRCRAFT

Two aircraft will be used for the airborne detection experiments, a King Air B200 turboprop and a Falcon jet.

3.1 King Air B200

The Atlantic Airways King Air B200 is equipped with the Litton APS-504(V)5 X-Band Search Radar. This radar was designed for small target detection (submarine periscopes) in moderate sea states (See specifications in Appendix A2-1). The radar has two main operating modes. The mode which is more suitable for the detection of the smallest targets has the shorter pulse length and is available on 12, 25 and 50 nmi range scales. The other mode uses a longer pulse and is available on 25, 50, 100 and 200 nmi. The longer pulse mode is intended for use against the larger targets. The radar data is digitally processed and displayed on the operator's 16 level green phospor display. A high resolution video cassette recorder (800 line) is used to record the operators display for later review on the ground. The VCR is equipped with an audio channel which is tied into the operator's microphone for commentary on the radar operation.

The radar is interfaced to an Omega navigation system. The aircraft position and velocity information provided by the Omega are used to position targets and to provide a Ground Stabilization mode of radar operation. The radar is in turn interfaced to an Hewlett-Packard 320 computer via a RS422 data link. The HP320 is used to log target positions and information. When the radar operator positions the active display cursor over a target of interest and hits a send key on a keypad the radar sends a data packet to the HP320 computer. The data packet includes target range and bearing, target lat. and lon., time and aircraft heading and position. A computer operator at the HP320 console may then add comments to the data string indicating the type of target if visual contact can be made. This record of detections is archived to disk and may be used subsequent to the flight to plot a map of target positions and the flight path. The aircraft is also equipped with a LORAN-C receiver which is also interfaced to the HP320. The HP320 can acquire aircraft position automatically every minute from the LORAN unit and store this data in a file for later analysis.

3.2 USCG Falcon

The USCG Falcon is equipped with FLAR and SLAR systems. The SLAR is an AN/APS-131 X-Band radar. This system (designated AIREYE) is equipped with a digital processing, display and recording capability. The AN/APS-127 X-Band FLAR is designed for air-to-surface search and weather detection tasks. Appendix A2-2 and A2-3 provide specifications of these radars. The Falcon is equipped with an inertial navigation system.

4. METHODOLOGY

The experiment methodology will follow that used by the USCG and by Nordco Ltd. on previous Search and Rescue experiments. A area of approximately 25 nmi. by 15 nmi. on the Canso Bank will be the site of the experiment. Life rafts will be deployed in a variety of patterns within this area and accurately positioned using a differential LORAN-C system (see Main Technical Plan). In order to accommodate the search capabilities of the aircraft the area searched will be greater for the aircraft than the surface vessel. Each life raft will contain an omni-azimuth Luneberg lens reflector having a 2 square meter radar cross section. It is intended for this target to represent the presence of a number of persons in the life raft. The lens reflectors have a vertical beam pattern that extends to 17 degrees above the horizontal at its 3 dB point. During each search the area will be overflown in a predetermined pattern and all target detections recorded. All radar settings will be noted by the observer on the aircraft and recorded on the log sheet along with target detections. Appendix A2-4 provides the log sheets to be used by the observers on the King Air and Falcon aircraft.

The flight schedule will depend on whether both aircraft are available on a particular day. When both are available a schedule similar to that provided in section 2.0 will be utilized to ensure maximum use of the both aircraft. Depending on the availability of a ship to move the life rafts it will be desirable to alter the position of some of of the life rafts between morning and afternoon flights. This will ensure the radar operators don't become familiar with the pattern of deployed targets and bias the data base.

4.1 Radar and Operational Parameters

The USCG Falcon is expected to concentrate on flying altitudes of 4000 feet as the USCG has found this to be an optimum altitude for SLAR. On the other hand they have also found that lower altitudes (500 feet) are more effective for the FLAR. A recent iceberg detection study which used the Litton radar also found a 500 foot altitude to be superior to 1500 feet for the detection of Bergy Bits. It is therefore intended to concentrate on the lower flying altitudes when using the Litton radar with most data to be collected at 500 feet altitude and some data to be collected at 1500 to 2000 feet.

As the number of flights will be limited it will be necessary to minimize the number of parameters that are varied over the experiment. This will ensure a maximum number of detection events occur for a given set of radar and environmental parameters. As a result the Litton radar will be operated in the mode that is expected to provide optimum performance for the detection of the life rafts. This will necessitate the operation of the radar in ground stabilized mode on the 25 nmi range scale using the short pulse. Frequency agility will be used along with scan to scan

processing. Clutter processing such as STC and CFAR will be used at the operator's discretion. Other radar controls, such as antenna tilt and threshold will be adjusted by the experienced operator to provide for best performance in a particular situation. If sufficient data is collected on the 25 nmi scale then data will be acquired using the 50 nmi. range scale at a 1500 or 2000 foot altitude.

4.2 Search Patterns

The selection of search patterns for the Falcon will be left up to the USCG team organizing their flights. NORDCO Limited will supply the USCG the limits (four corners) of the search area on a particular day. The vertical pattern of the reflector mounted in the life rafts will limit the closest range that the aircraft may fly at a particular altitude.

The search patterns to be utilized for the Litton radar are expected to be highly variable at the beginning of the experiment as the performance of this radar against these type of targets has yet to be assessed. Once the potential detection range for these targets has been identified patterns will be chosen to ensure that sufficient detection opportunities occur in all the lateral range bins.

4.3 Navigation

While both aircraft have onboard navigation systems it will be necessary to provide a reference in the data set to ensure any positional errors or differences can be accounted for during track reconstruction. This will be accomplished by using either the search vessel or the buoy tender (if available) as a large reference radar target. It will be critical that the position of the reference vessel be known as it is overflown by the aircraft and that the aircraft and vessel position can be time synchronized. Tentatively this will be accomplished by having the reference vessel stand by the LORAN-C buoy as the airborne search is carried out.

4.4 Communications

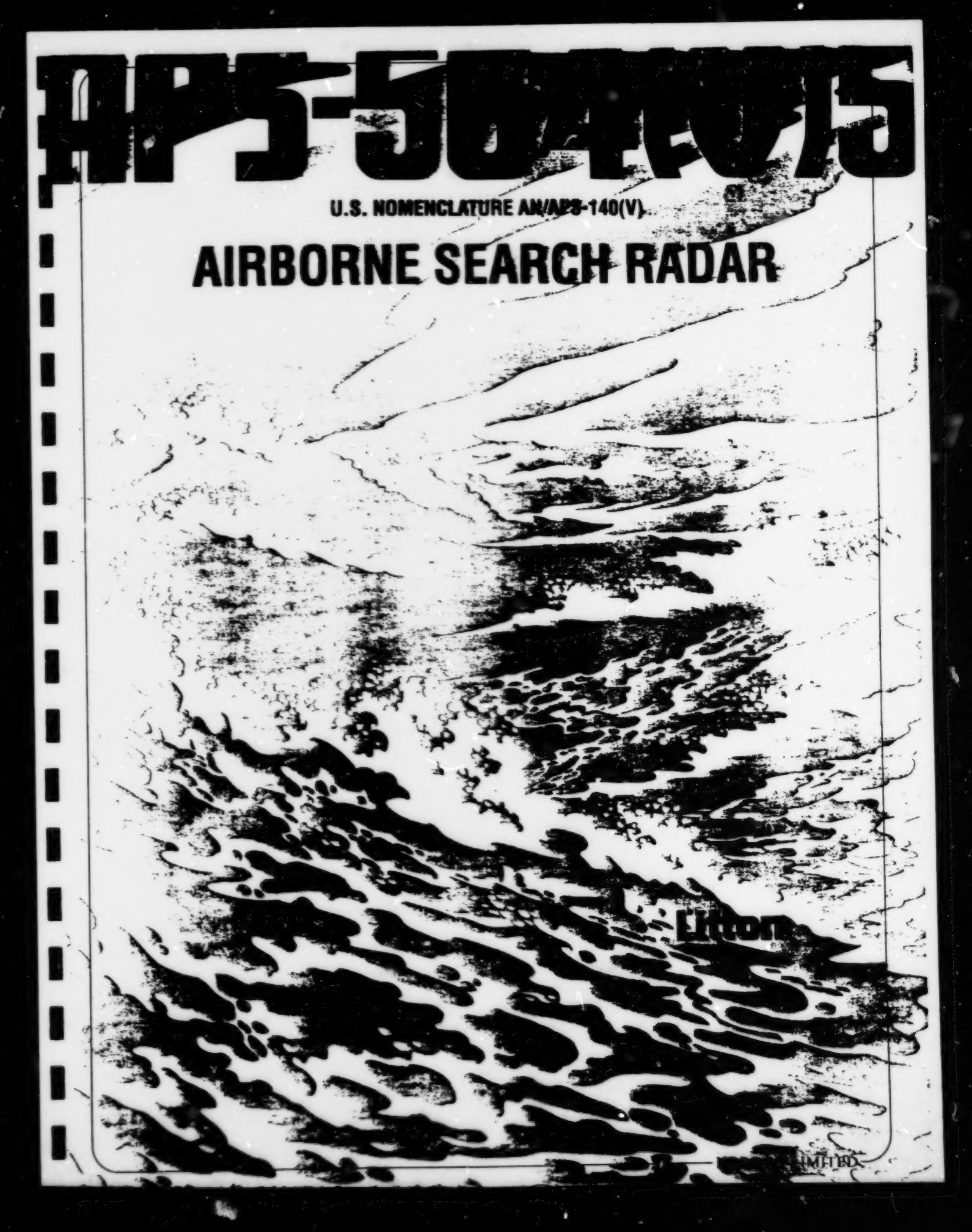
Communication with the aircraft when in the search area will be through the CCGS "Alert" using VHF radio. Shore based personnel will communicate with the "Alert" from Coast Guard Radio at Ketch Harbour. Coordination of aircraft departure times will be accomplished via phone communication between Atlantic Airways facilities at Halifax International Airport and Ketch Harbour and CFB Shearwater and Ketch Harbour.

APPENDIX A2-1
Litton APS-504(V)5
Surveillance Radar

AP5-50A-015

U.S. NOMENCLATURE AN/APS-140(V)

AIRBORNE SEARCH RADAR



APS-504(V)5

AIRBORNE SEARCH RADAR

With digital Display Subsystem, Pulse Compression and Frequency Agility.

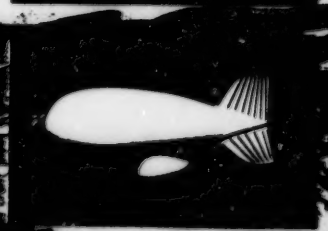
General Characteristics

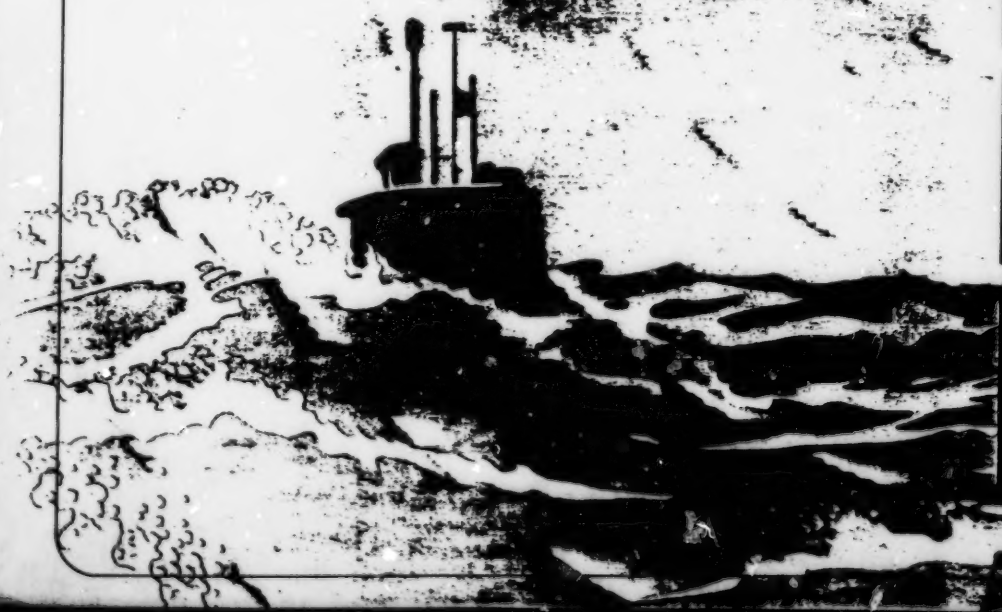
The APS-504(V)5 and the AN/APS-140(V), are ASW class airborne search radars designed for tactical and maritime surveillance roles, suitable both for fixed-wing aircraft and helicopters. Employing pulse-compression and frequency agility, either will provide optimal detection of small targets in high sea states and provide considerable immunity to ECM. In addition to a high capability in sea search, either the APS-504(V)5 or the AN/APS-140(V) can be used in ground mapping, navigation, station-keeping and weather avoidance roles.

Both have TV-type raster displays, visible in cockpit light, that provides a high-definition non-fading display, with an alphanumeric overlay, capable of being frozen indefinitely. The display can accommodate any tactical data which is in suitable RS343A 875-line format, or can interface to the system via a variety of data bus interfaces. The in-flight recording capability will playback either in the air or on the ground, is applicable for analysis, critiques and training, as well as in-flight assessment of a tactical area.

Built-in test capabilities facilitate first-line servicing. Special-to-type unit test and system test sets are available for second-line servicing.

The APS-504(V)5 and the AN/APS-140(V) airborne radar systems are the newest members of the Litton Systems Canada Limited family of APS-504 radars. Both enhance the detection capability of the internationally field-proven (V)2, and couples it with the digital processing, high definition and versatile raster display of the (V)3 system; the (V)5 is advanced successor.

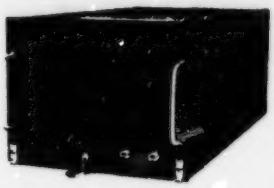


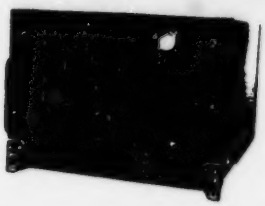


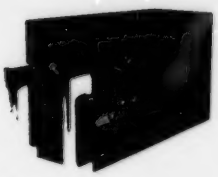
RECOMMENDED

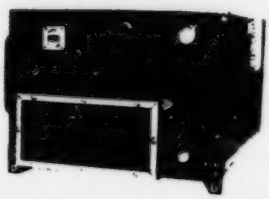
APS-504(V)5 SYSTEMS CONFIGURATION

- Antenna group
- Power Amplifier Unit (PAU)
- Exciter/Receiver Unit (ERU)
- Digital Filter Preprocessor (DFP)
- Synchronizer, Processor and converter (SPC)
- Digital TV Display RS343A, 875 lines
- Radar Control Unit (RCU)



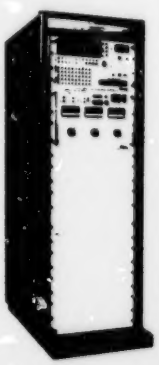


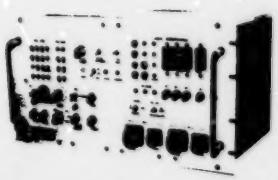


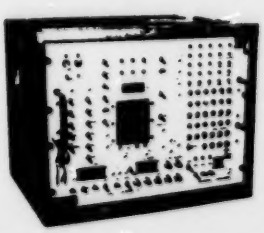


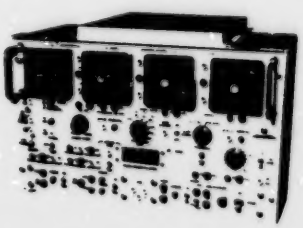
TEST EQUIPMENT

- **System Test Set enables complete system to be activated and tested.**
- **System Test Set simulates all aircraft provided inputs.**
- **Unit Test Sets enable individual LRU's to be exercised and tested.**



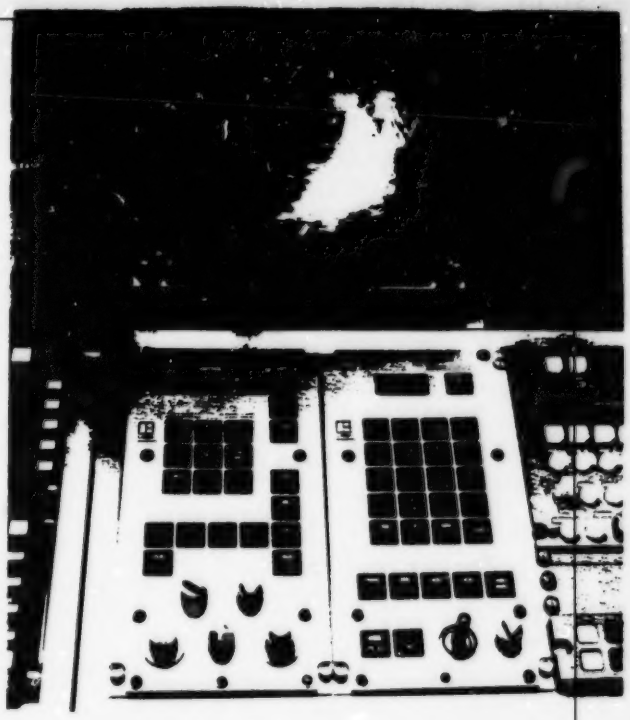






APS-504(V)5 and AN/APS-140(V) FEATURES

- Pulse Compression utilizing advance SAW technology (500:1 and 210:1 PC ratios)
- Wide Band Frequency Agility (500MHz)
- Scan to scan integration
- Travelling Wave Tube (TWT) amplifier
- STC at R.F.
- Receiver noise figure 4 dB
- Beacon mode/search mode/ search F.A. mode/weather mode
- Digital X-Y Display viewable in high ambient light
- Video Processing
- Display Alphanumerics
- Sector Scan - variable width
- Range Delay
- Offset Sweep
- Sweep Expansion
- Stabilized Antenna
- True Motion Display - using inputs from navigation system
- ARINC 571 and 429 digital interface
- Extensive BITE



Complete Range of Integrated Logistics Support Available

- Operator and maintenance training
- Field Service Engineering
- Life Cycle Support
- Logistics Documentation
- Reliability and Maintainability Engineering
- Repair and Overhaul

Ancillary (Optional) Units

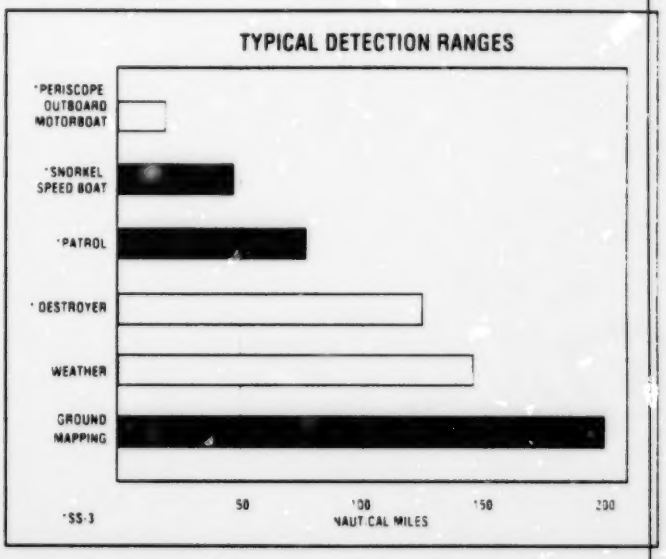
- Cockpit Repeater Display and Control Unit
- Video Tape Recorder (full display radar and alphanumerics) recorded on video tape for playback in the aircraft or on the ground.

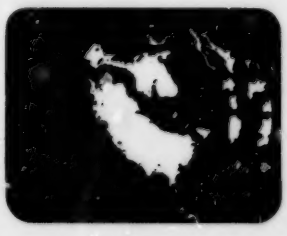
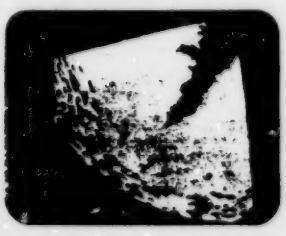
Available Options

- Track-While-Scan (TWS)
  Data file up to 20 contacts can be acquired and displayed with automatic range bearing alphanumeric readout. Tracking symbol with tag will follow contact on the display
- IFF interrogation and video response display
- ESM strobe display
- MIL-STD-1553B RT interface with remote control capability
- RS-422 interface

Growth Capability

- Target Position reporting to an onboard computer
- Target position reporting over air to ground data link
- Synthetic aperture (SAR)
- Pulse Doppler



TECHNICAL CHARACTERISTICS

ANTENNA GROUP

Type

Advanced 3-axis pedestal.
2-axis pedestal optional.

Stabilization

Limits depend on installation requirements.
3-axis pedestal:
± 20 degrees in Pitch and
± 40 degrees in Roll.
2-axis pedestal:
± 20 degrees in both Pitch and Roll at antenna speeds up to 30 rpm only.

Tilt

Up to ± 16 degrees, variable by operator. Limits depend on actual installation mechanical restraints.

Rotation Rate

7.5 - 120 RPM in 8 rates. Automatically selected to match Range/Mode combinations in turbulence.

Sector Scan Width

30 - 120 degrees, variable by Operator selection, or continuous rotation.

Antenna

Antenna type dependent on installation requirements.
Gain is typically 32 dB.
Far-out azimuthal side lobes: -40 dB.

Built-In-Test

Monitoring of all servo-loops.

Options

Low sidelobe, broadband, flatplate antenna.
Spotlight mode.
Bi-directional (reversing) sector scan.
IFF or ESM antenna integrated with radar antenna.

TRANSMITTER/ RECEIVER GROUP

Frequency

8.9 - 9.4 GHz range, with 2 frequency agility patterns.
16 fixed frequencies selectable by operator.

Power Amplifier

Pulsed TWT, 8 kW peak power.

Transmit Modes

Two pulse-compression modes, three non-compressed modes for short-range navigation weather and beacon.

Pulse Compression

500:1 and 210:1 pulse compression ratios with non-linear chirps.
30 and 200 ns compressed pulse widths.

Noise Figure

5 dB maximum; 4 dB typical for receiver.

STC

STC at RF, variable by operator.

Receiver

GaAs FET low-noise RF amplifier followed by image-rejection mixer.
Matched IF filters mode selected including 2 pulse compression modes.
Beacon mode: receive 9310 ± 7 MHz.

Synchronization

Timing and frequencies derived from a master oscillator.

Built-In-Test

Extensive monitoring of TWT operation and general functions.

OPERATOR'S DISPLAY

Display Type

P43 phosphor, or similar for high ambient light viewing.
875 lines per frame - per RS 343A.
2:1 with 30 Hz refresh.
16 grey scale levels.
Digital X-Y TV presentation.
25.4 cm diagonal.

Compass Rose and Aircraft heading marker available in some overlay modes. Display is aircraft or north referenced.

Range Scales

3-200nmi in 7 ranges.

Range Rings

1-50 nmi depending on range selected.

ALPHANUMERICS

Available in overlay to left of PPI display.

SYNCHRONIZER, PROCESSOR & SCAN CONVERTER UNIT

Functions

System sync. and timing.
Rho-Theta to X-Y conversion.
Standard Digital signal processing:
CFAR Azimuth filter
Pulse-to-pulse integration
Scan-to-scan integration
Display refresh memory for Radar data 1024 x 1024 x 4 bits.
Alphanumeric and Graphic generation with 512 x 512 x 1 bit overlay.
Composite video generation per RS 343A.
ARINC 571/429 interface with dual speed I/O ports.

Options

ESM blanking.
IFF trigger and display.
Track-While-Scan.
RS 422 interface.
MIL-STD-1553B RT interface.

OPTIONAL UNITS

Video Cassette Tape Recorder

875 Line to RS 343A standard.

Pilot Display & Control Unit

Provides full repeat of Operator's Display.
TV 875 line to RS 343A standard.
12.7 cm diagonal, with Isoecho weather display.

RADAR INTERFACE REQUIREMENTS

Heading

3 wire synchro to ARINC 407.

Pitch/Roll Stabilization

2 wire resolver or 3 wire synchro to ARINC 407, either acceptable.

NAV Data

ARINC 571 or ARINC 429
N-S/E-W Velocity and Ground speed.
Present Position Latitude/ Longitude.

POWER & WEIGHT REQUIREMENTS

Power

115 VAC, 400 Hz 3-phase, 1.5 KVA to MIL-STD-704A.
28 VDC, 15 Amperes to MIL-STD-704A.

Weight

All-up weight with the 3-axis pedestal is 400 pounds.

For further information contact Radar Marketing Department.

Litton

Litton Systems Canada Limited

25 City View Drive, Etobicoke, Ontario, Canada M9W 5A7

TEL: (416)249-1231 TELEX 06-989408/TWX 610-492-2110/ FAX (416) 248-5488

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NORDCO LIMITED

APPENDIX A2-2
MOTOROLA AN/APS-131
SLAR

AN/APS-131 SLAR

Item	Overall Dimensions (in.) Height	Width	Depth	Overall Weight (lbs)
SLAR Control	9.00	5.75	9.00	10
Synchronizer	7.84	15.52	20.12	50
Receiver-Transmitter	7.84	15.52	20.12	75
Amplifier - Power Supply	7.84	10.26	13.12	30
Antenna	30.50	12.50	166.25	229
Recorder	21.00	14.50	27.29	103
			Total SLAR Weight	513

Overall System

Maximum Range	80 nmi
Resolution	
Range	30 meters (98 ft)
Azimuth	1.0°
Input Power Requirements	
AC	115 volts (line-to-neutral) 3 phase, 400 Hz, 10 A/phase
DC	+28 V, 20 A

Transmitter

Carrier Frequency	9250 ±1 MHz
Peak Power (at transmitter output)	185 kW (min)
Average Power	55.5 W (min at 1500 pps) 27.5 W (min at 750 pps)
Modulation	Pulse
Pulse Width	0.2 ±0.025 μs

Pulse Repetition Rate:	
Fixed Rate	750 or 1500 pps
Pseudorandom Rate	1,333.33 ±44.4 µs or 666.7 ±22.2 µs
Duty Cycle	0.015% at 750 pps 0.03% at 1500 pps

Receiver

Frequency	9250 ±1 MHz
IF Frequency	120 MHz
IF Bandwidth	6 ±0.25 MHz at 3 dB
Sensitivity (minimum discernible signal)	-101 dBm

Antenna

Beamwidth (horizontal)	0.95 ±0.05, -0.10° between half-power points
Pattern (vertical)	Cosecant squared (±1.5 dB) over a depression angle from 4° to 45°
Sidelobes:	
Azimuth	20 dB min below mainbeam peak
Elevation	25 dB min below mainbeam peak
Backlobes	34 dB min below mainbeam peak
Polarization	Vertical
Gain	31 dB min
VSWR	1.2:1 max
Operating Altitude	20,000 ft (6097 meters) max

SLAR Dry Silver Film

Type of Target Indicator	Modified ppi using two fiber-optic coupled CRT displays
Display Range	13.5, 27, 54, and 80 nmi
Resolution	30 lines/mm min
CRT Trace Length	39.5 ±0.05 in. (10 ±0.13 cm)
CPT Trace Correction	Correction for aircraft drift angles over ±15° within ±0.65°. Correction for radar beam squint

APPENDIX A2-3
TEXAS INSTRUMENTS AN/APS-127
FLAR

RADAR PARAMETERS

Transmitter/Receiver

Transmitter

Frequency – 8.8 to 9.6 GHz, manually tunable with 60 MHz agility

Power output – 200 KW peak (nominal)

Mode	Pulsewidth	PRF
Long pulse	2.5 microseconds	400 Hz
Short pulse	0.5 microsecond	1600 Hz

Receiver

Noise figure	7.5 dB maximum
Low Noise Option	5.5 dB maximum
IF amplifier	
Type	Logarithmic
Dynamic range	100 dB
Center frequency	60 MHz
Bandwidth	
Long pulse	0.5 MHz
Short pulse	2.5 MHz

Antenna

Scan rate — Long pulse – 12 rpm — Short pulse – 120 rpm

X-Band

Gain	30.0 dB (nominal)
Azimuth beamwidth	5.0 degrees
Elevation beamwidth	6.5 degrees
Sidelobes	Down at least 20 dB
Polarization	Horizontal
Bearing accuracy	Better than ±1.0 degree

IFF

Standard IFF interrogator sets
Monopulse compatible

Displays

	Observer	Pilot (Cockpit)
Display type	Direct view storage tube	Direct view storage tube
Display diameter	7 inches	5 inches
Resolution	75 lines/inch	85 lines/inch
Persistence (adjustable)	0.5 to 10.0 seconds	0.25 to 9.0 seconds
Shades of gray	5	5
Cursor Accuracy		
Range	±2 percent of selected range	
Azimuth	±2 degrees	

SERVICE CONDITIONS

The APS-127 is designed to operate satisfactorily under any of the environmental service conditions or reasonable combinations of these conditions as specified in Specification MIL-E-5400, Class 1 equipment except as modified below.

A. Vibration

The equipment shall operate satisfactorily when subjected to the vibration requirements of Figure 2, Curve I of MIL-E-5400, with acceleration limited to ±2 *g* maximum.

B. Temperature

The equipment operating extreme temperature range shall be –25°C to +55°C. Equipment shall operate with degraded performance allowed from –54°C to –25°C. The equipment operating extreme temperature range for the synchronizer and antenna units shall be –54°C to +55°C.

C. Altitude

The equipment shall operate satisfactorily at all altitudes between sea level and 45,000 feet.

D. Humidity

The equipment shall operate satisfactorily in 95-percent relative humidity at +55°C for 48 hours.

INTERFACE REQUIREMENTS

Power input 115 VAC	400 Hz, three-phase 1950 VA MIL-STD-704A aircraft power
28 VDC	3A MIL-STD-704A aircraft power
Pitch, roll input	3-wire synchro
Ground stabilization input Compass heading input	Interface designed to match output available from customer-furnished equipment

Antenna Parameters

- RADAR RF

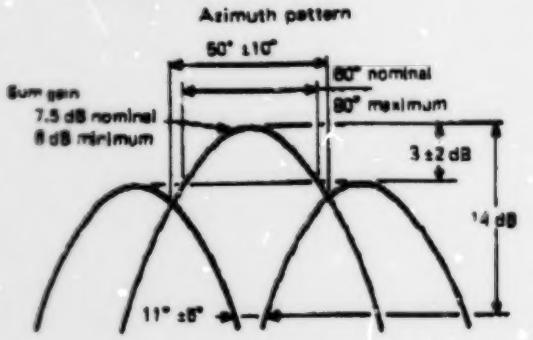
Gain	29.0 dB minimum
Sidelobes	Down at least 20 dB
3 dB beamwidth	5.0 degrees (AZ) maximum
	6.5 degrees (EL) maximum
Polarization	Horizontal

- MECHANICAL

Roll limits	±40 degrees
Pitch limits	+10, −20 degrees
Azimuth scan	12 or 120 rpm
Tilt limits	+10, −20 degrees

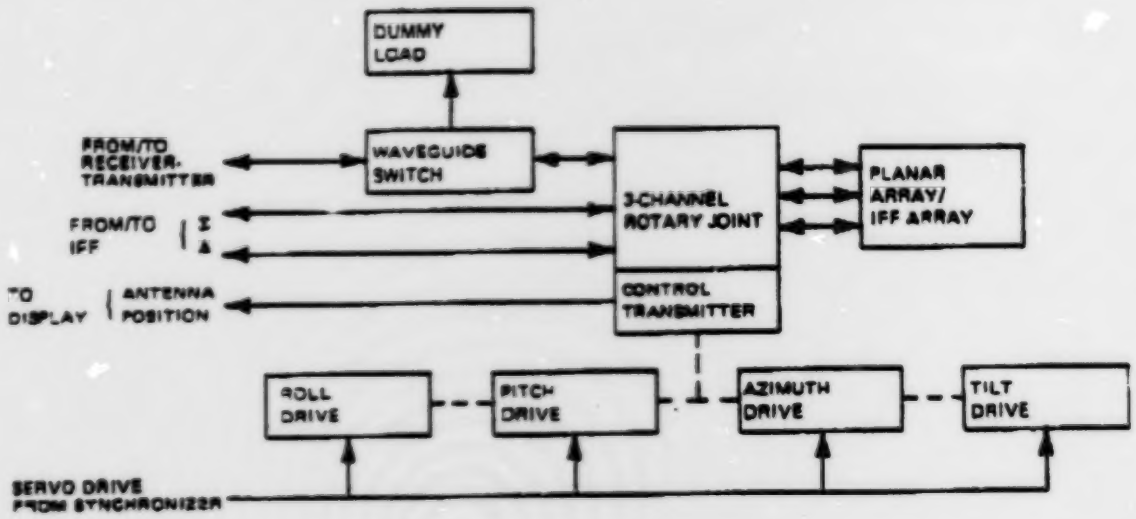
- IFF

Standard IFF interrogator sets
Monopulse compatible



Elevation beamwidth	55° nominal, 80° maximum
Polarization	Vertical

Functional Block Diagram



Physical Characteristics

- Size (inches) 24.00 H X 29.00 W X 17.00 D
- Weight (pounds) 32.0
- Power Dissipation (watts) 150

APPENDIX A2-4
Log Sheets

APS-504 (V) 5 DETECTION LOG

Page __ OF __

King Air B200 _____ PPI Setup/System Operating Mode DATE _____

Radar Operator _____ STC - ON/OFF DISPLAY - REL/NORTH/GND SEARCH _____

OBSERVER _____ FREQ. - FIXED/AGILE CFAR - ON/OFF SPEED _____

PULSE - SHORT/LONG S-TO-S - OFF/FF/SS ALTITUDE _____

DETECTION/ LEG NUMBER	DETECTION/TURN TIME	DETECTION RANGE (nmi)	TARGET BEARING (deg T/R)	RANGE SCALE (nmi)	HEADING (deg T/M)	REMARKS

APPENDIX B

CHRONOLOGY OF EVENTS

DETAILED CHRONOLOGY OF THE OFFSHORE SAR DETECTION EXPERIMENT

PART I

Friday, November 4 - Monday, November 7, 1988

Equipment was mobilized at NORDCO Limited on Friday, November 4, 1988. Mr. Lundy and Mr. Tucker of NORDCO Limited departed St. John's in the early morning of Saturday, November 5, aboard a Ryder rental truck and arrived Dartmouth on Sunday afternoon, November 6. Mr. Finlayson and Mr. Fagan of NORDCO Limited departed St. John's by air on Sunday, November 6, and met Mr. Lundy and Mr. Tucker Sunday evening.

On the morning of Monday, November 7, all life rafts, moorings, buoys, and life raft servicing equipment were placed aboard Canadian Coast Guard Ship (CCGS) "Sir William Alexander" at the Canadian Coast Guard (CCG) base in Dartmouth. NORDCO personnel then proceeded to Shearwater and put the remaining equipment aboard the CCGS "Alert".

On the CCGS "Sir William Alexander" all equipment was secured in the forward hold. On the CCGS "Alert" all receiving antennas were installed on the "Monkey Island" directly above the bridge while the computer equipment was secured in the communications room directly aft of the bridge.

Tuesday, November 8, 1988

The CCGS "Alert" departed Shearwater in the morning enroute to Liscombe Harbour under the command of Captain J. McKenna. Mr. Lundy and Mr. Tucker were on board.

The CCGS "Sir William Alexander" departed Dartmouth enroute to the Canso Bank at 1600 AST under the command of Captain Eric Hann. Mr. Finlayson and Mr. Fagan were on board.

Wednesday, November 9, 1988

The CCGS "Sir William Alexander" arrived on the Canso Bank at 0700 AST. By 0952 AST five life raft moorings had been deployed in water depths ranging from 66-73 metres(m). The Loran-C buoy was deployed at 1055 AST without incident. The buoy was deployed on a taut mooring with a ground line attached to a spar buoy mooring 140 m from the Loran-C buoy on a bearing of 019 ^{o}T. The wave measuring buoy was initially deployed at 1123 AST in a water depth of 65 metres using a 2:1 scope mooring and a ground line attached to a spar buoy. Unfortunately, the ground line became tangled in the bow thruster and the wave buoy was dragged 0.5 nautical miles (nmi) before the vessel stopped. After numerous attempts to free the mooring, the wave buoy was brought back aboard. In an effort to retrieve the spar buoy and mooring, the phenolic block linking the mooring to the anchor parted and the spar buoy and mooring were lost. Meanwhile, the groundline was still tangled in the bow thruster with the anchor firmly

attached. At this point, it was decided by Captain Hann to proceed to Mulgrave and have the ground line removed from the bow thruster by divers. The CCGS "Sir William Alexander" departed the Canso Bank enroute to Mulgrave at 1552 AST.

The CCGS "Alert", enroute from Liscombe Harbour to Mulgrave while the CCGS "Sir William Alexander" was on the Canso Bank, determined that the transmission from both the wave buoy and the LORAN-C buoy appeared to be normal.

At 1958 AST the CCGS "Sir William Alexander" tied up in Mulgrave while the CCGS "Alert" tied up at the Canso lock later that evening.

Thursday, November 10, 1988

NORDCO personnel, J. Russell and K. Elliott, together with W. Reynolds of United States Coast Guard (USCG) arrived aboard the CCGS "Alert" at 0800 AST. Mr. R. Tucker departed the CCGS "Alert" and returned to St. John's.

At 1120 AST both the CCGS "Sir William Alexander" and the CCGS "Alert" departed Mulgrave and Canso lock, respectively. The CCGS "Sir William Alexander" headed to the Canso Bank with NORDCO personnel D. Finlayson and A. Fagan aboard. The CCGS "Alert" with NORDCO personnel J. Russell, J. Lundy and K. Elliott together with W. Reynolds of USCG on board headed to the Country Harbour anchorage to await deployment of remaining moorings by the CCGS "Sir William Alexander". Prior to proceeding to Country Harbour, the CCGS "Alert" went to Mulgrave to pick up five life rafts that had been purposely left on the dock by the CCGS "Sir William Alexander".

At 1504 AST the wave buoy was deployed using a single 2:1 scope mooring in 65 m of water. By 1712 AST five more life raft moorings had been deployed.

At 1716 AST the CCGS "Sir William Alexander" departed for Country Harbour to rendezvous with the CCGS "Alert". At 2100 AST the CCGS "Sir William Alexander" arrived in Country Harbour and NORDCO personnel D. Finlayson and A. Fagan were transferred to the CCGS "Alert". The CCGS "Sir William Alexander" then headed to Dartmouth CCG base while the CCGS "Alert" remained anchored in Country Harbour. At this point, in addition to the officers and crew of the CCGS "Alert", five NORDCO Limited personnel and one USCG representative were on board. Specifically, they were:

Mr. K. Elliott	NORDCO Limited
Mr. A. Fagan	NORDCO Limited
Mr. D. Finlayson	NORDCO Limited
Mr. J. Lundy	NORDCO Limited
Mr. J. Russell	NORDCO Limited
Lt. W. Reynolds	USCG

Friday, November 11, 1988

At 0830 AST the CCGS "Alert" tied up at the Government wharf in Country Harbour. Due to strong to gale force southwesterlies it was decided that no useful work could be accomplished that day on the Canso Bank. The remainder of the day was spent making general preparations for the search experiment. During the afternoon, Lt. W. Reynolds of USCG briefed the seamen on the use of night vision goggle systems while Mr. D. Finlayson of NORDCO Limited discussed the main points of the experiment with the same group. The CCGS "Alert" remained tied up overnight.

Saturday, November 12, 1988

The CCGS "Alert" departed Country Harbour at 0730 AST and arrived at the LORAN-C buoy at 1215 AST. Seas at that time were running 2.4 m significant height with winds from the west-northwest at 30 knots. It was decided that conditions were too rough to put the Fast Rescue Craft (FRC) in the water to deploy life rafts. The remainder of the day was spent checking out the navigation system. It was found that the LORAN-C buoy was sending time differences (TD's) from the 7930 chain and not the 5930 chain. The LORAN-C buoy would have to be recovered at the first opportunity and then reset and redeployed. The CCGS "Alert" departed Canso Bank at 1530 AST and anchored in Chedabucto Bay at 1905 AST.

Sunday, November 13, 1988

The CCGS "Alert" departed Chedabucto Bay at 0330 AST and arrived on the Canso Bank at 0700 AST. Wave heights were running 1.5 m significant height with the winds out of the north at 13 knots.

The LORAN-C buoy was recovered at 0834 AST using the FRC, it was redeployed at 1021 AST. Initial TD's from the LORAN-C buoy were found to be in error by large amounts. No explanation for this was immediately available. The first life raft was deployed at 0904 AST. The life rafts were deployed from the port side rescue deck. From past experience, it was obvious that the CCGS "Alert" was not as suited for deployment of life rafts as was the CCGS "Sir William Alexander". By 1355 AST eight life rafts had been deployed with their exterior lights operating normally. Of the eight life rafts deployed, six were equipped with Lensref radar reflectors in preparation for air searches later in the week. One of the moorings, deployed on November 09, could not be located. The remainder of the afternoon was spent making final preparations for the first search which was scheduled to commence at 1800 AST on November 13.

Surface search 01 began on November 13, at 1805 AST and ended at 0027 AST on November 14. This first search was a night search using Litton model 915A night vision goggles (two image intensifier modules). Winds at the beginning of the search were from the south at 9 knots and by the end of the search had increased to southerly 26 knots. Significant seas were

running at 0.6 m at the start of the search and had increased to 1.1 m by the end of the search. Visibility was good throughout the search, being 15 nmi or better.

Monday, November 14, 1988

Surface search 02 began at 0128 AST. At 0445 AST the life raft light at mooring 11 was checked and was found to be out. At this time, it was assumed that all light batteries would be flat. As a consequence, the search was ended. Surface search 02 was carried out using the same night vision goggles as in surface search 01. The wind during the course of the search backed from south to south-southeast and remained between 25-30 knots throughout. Seas increased throughout the search from a 1.1 m to a 2.2 m significant wave height with an increasing southerly swell of 1.5 m being established by the end of the search. Visibility was 15 nmi during all except the last hour of the search when the visibility had decreased to 7 nmi in light rain.

Surface search 03 began at 0918 AST, and ended at 1202 AST. This day search was terminated in order to give the lookouts a break before the night search scheduled for 0000 AST on November 15. Winds during the search were generally southeast at 35 knots but during the last hour had veered to south-southwest and dropped to 29 knots. Seas started out at 3.3 m significant wave height at the beginning of the search and had increased to 4.4 m by the end of the search. During the first hour of the search the visibility was between 1 and 1 1/2 nmi but during the last two hours had decreased to ranges of 1/4 to 3/4 nmi light rain and fog.

The CCGS "Alert" departed the Canso Bank at 1205 AST and anchored in Chedabucto Bay at 1510 AST. The anchor was hauled at 2030 AST and the CCGS "Alert" departed for the Canso Bank arriving shortly before midnight.

Tuesday, November 15, 1988

Surface search 04 began at 0001 AST and ended at 0525 AST. The search was a night search for unilluminated life rafts using Model 915A night vision goggles (two image intensifier modules). Winds during the search were out of the west-southwest at 20-25 knots. Significant wave heights were averaging near 3 m and this was made up mainly by a south-southwest swell that was running near 3 m. Visibility was 15 nmi throughout the search.

Surface search 05 began at 0804 AST and ended at 1335 AST. The wind during the search was from the west to west-northwest at speeds between 25-31 knots. The significant wave height was near 2.5 m and the visibility was 15 nmi throughout the search.

Surface search 06 began at 1353 AST and ended at 1624 AST. Winds during the search were from the west to west-northwest at speeds near 30 knots. The significant wave height was near 2.5 m and the visibility was 15 nmi with some very light showery precipitation occurring.

At the completion of surface search 06 the CCGS "Alert" set a course for Mulgrave where it tied up at 2030 AST. Immediately, prior to docking, smoke was seen coming from the inner seal of the stern tube on the port shaft. Coast Guard personnel were unsure of the full extent of the problem but initially it was estimated that repairs would take at least two days.

Wednesday, November 16, 1988

The CCGS "Alert" remained tied up in Mulgrave. Ship's engineers worked on the shaft seal problem. The NORDCO group aboard worked at getting the SAR detection data entered into computer files.

NORDCO personnel J. Lundy and A. Fagan travelled to Dartmouth and boarded the CCGS "Sir William Alexander." The vessel, under the command of Captain W. Frampton, departed for the Canso Bank at 2000 AST to service the life rafts.

Thursday, November 17, 1988

Life rafts were serviced in the morning and the LORAN-C buoy was changed with the spare unit. Prior to the Atlantic Airways first airborne radar search, the following life raft status existed:

- 9 life rafts in the water
- 7 Lensref reflectors mounted in life rafts
- 1 transponder attached to life raft

Following deployment the transponder was detected at 3.5 nmi with steady return signal noted at ranges less than 2.8 nmi.

Airborne search 01 took place at 1600 AST. Wind conditions at the time were from the south at 25 knots with a 1.5 m significant wave height. The CCGS "Sir William Alexander" stood by the LORAN-C buoy during the search and TD's were recorded every minute. The airborne search ended at 1656 AST.

On the CCGS "Alert" Coast Guard personnel were tending to repairs while remaining NORDCO personnel spent time in modifying the computer program for search reconstruction.

Friday, November 18, 1988

With southerly gales of 40-45 knots the CCGS "Sir William Alexander" sought shelter and departed the Canso Bank for Chedabucto Bay at 0400 AST. The CCGS "Sir William Alexander" departed Chedabucto Bay at 0900 AST and arrived at the Canso Bank near noon. During the high winds overnight two life rafts had collapsed and two Lensref reflectors had been lost leaving a total of 5 Lensref reflectors for the scheduled Atlantic Airways airborne search that afternoon.

At 1329 AST the CCGS "Sir William Alexander" made contact with the Atlantic Airways flight. Atlantic Airways advised that they would be on site at 1400 AST. At 1402 AST Atlantic Airways advised the CCGS "Sir William Alexander" that the mission was being aborted due to navigation problems. After the aborted airborne search the CCGS "Sir William Alexander" headed for anchorage at Chedabucto Bay arriving at 1800 AST. AT 1820 AST the CCGS "Sir William Alexander" was assigned to a SAR mission on the Banquereau Bank.

Seal repairs were still being attended to aboard the CCGS "Alert". Repair estimates indicated that a further 2 days would be necessary to affect temporary repairs and conduct sea trials.

Saturday, November 19, 1988

A shaft seal test was conducted on the CCGS "Alert", the repair work was found to be acceptable. The CCGS "Alert" departed Mulgrave near noon and arrived in Country Harbour at 1800 AST. The CCGS "Alert" was to remain in Country Harbour until the arrival of Mr. Fitzgerald of NORDCO Limited and Dr. Paul Stager of York University. Dr. Stager was assigned to the experiment to report on human factors affecting marine SAR detection work. The aircraft navigation system was also repaired.

On the Banquereau Bank, a tow line was attached from the CCGS "Sir William Alexander" to the distressed vessel at 0700 AST. The vessel was towed to Louisbourg. The tow was released at 1800 AST at which time the CCGS "Sir William Alexander" proceeded to Mulgrave to change out Commanding Officers. Weather conditions during the tow were 50-60 knot winds with seas running 5-7 m.

Sunday, November 20, 1988

The CCGS "Sir William Alexander" changed out Commanding Officers at 1000 AST with Captain Hann relieving Captain Frampton. The CCGS "Sir William Alexander" then proceeded to the Canso Bank to retrieve all life rafts in advance of a developing storm system.

At 1430 AST Mr. Dawe and Mr. Fitzgerald of NORDCO Limited together with Dr. Stager arrived at the CCGS "Alert" in Country Harbour. Mr. Dawe departed for Dartmouth at 1700 AST.

At 1730 AST a life raft status report was received from Mr. Lundy of NORDCO Limited aboard the CCGS "Sir William Alexander". Mr. Lundy reported that all life rafts had been recovered but only four were serviceable. The remaining life rafts were either destroyed or beyond economical repair.

In view of the life raft status and the pending storm, Mr. Finlayson, the NORDCO field manager, suggested to Mr. Dawe, the project manager, that now may be the opportune time to terminate Part I of the experiment.

Monday, November 21, 1988

Mr. Dawe of NORDCO Limited, after discussions with Mr. B. Leonard of Coast Guard, advised NORDCO personnel to shut down Part I of the experiment.

Mr. Lundy and Mr. Fagan departed the CCGS "Sir William Alexander" in Mulgrave and proceeded to pick up the remaining NORDCO personnel aboard the CCGS "Alert" in Country Harbour. All NORDCO personnel together with Dr. Stager departed the CCGS "Alert" at 1600 AST enroute to Halifax airport.

End of Part I

PART II

Wednesday, November 30, 1988

In the late evening, Mr. A. Fagan and Mr. R. Tucker of NORDCO Limited arrived aboard the CCGS "Sir William Alexander", which was docked at the CCG base in Dartmouth, Nova Scotia.

Thursday, December 1, 1988

Mr. Fagan and Mr. Tucker carried out repairs to the life rafts in preparation for Phase II of the experiment. There was a total of ten usable life rafts consisting of seven four-man Beaufort, two six-men Beaufort and one six-man Dunlop.

The CCG delayed the sailing of the CCGS "Sir William Alexander" until 1700 AST, December 2, in order to transfer fuel from the CCGS "William" to her.

The CCGS "Alert" was holed above the water line on the port side while docking at Shearwater and had to undergo repairs. The CCGS "Alert" was made available for only forty-eight hours at the experiment site due to further problems with leaking shaft seals.

Friday, December 2, 1988

The CCGS "Sir William Alexander" departed the CCG Dartmouth base at 1700 AST under the command of Captain E. Hann bound for the Canso Bank experiment site.

Mr. R. Fitzgerald, Mr. J. Russell, and Mr. K. McCarthy of NORDCO Limited and Dr. Stager arrived aboard the CCGS "Alert" at 2200 AST. The CCGS "Alert" departed the CCG Dartmouth base at 2230 AST under the command of Captain J. McCann, bound for the Canso Bank experiment site. The ship proceeded at reduced speed because of the problem with leaking shaft seals.

Saturday, December 3, 1988

The CCGS "Sir William Alexander" arrived on the Canso Bank at first light, and began a survey of the moorings. Life raft moorings 4, 5 and 10 were missing. New moorings were layed at these positions and at mooring position 8. All the remaining life raft moorings were intact. The survey confirmed ten life raft moorings in place at mooring positions 4,5,6,8,9,10,11,12,13, and 14. The wave buoy and LORAN-C buoy were still at their original mooring position and appeared to be in good condition.

Life rafts were deployed from the CCGS "Sir William Alexander" beginning 1300 AST. A total of ten illuminated life rafts without radar reflectors were deployed. The life raft on mooring 14 had a floating radar

transponder (Mitsubishi Electric Co. X-Band Melsweep Model-H) attached to it. A second transponder of the same type had stability problems and had to be lashed upright to the outside of the life raft on mooring 9. The CCGS "Sir William Alexander" finished deploying life rafts at 1630 AST then steamed into Chedabucto Bay and anchored for the night.

The CCGS "Alert" arrived on the Canso Bank at 1500 AST. Surface search 07 began at 1716 AST December 3 and ended at 0200 AST, December 4, 1988. This was a night search for illuminated life rafts using Litton model M972 night vision goggles (one image intensifier module). Winds were westerly at the beginning of the search and had backed to south-southwest by the end of the search. Wind speeds were between 13 and 26 knots throughout the search with significant wave heights of 1.6 to 1.9 m. Visibility was greater than 15 nmi for the first half of the search and dropped to 10-12 nmi in rain showers during the last half of the search. LORAN-C reception was erratic throughout the search.

Sunday, December 4

Surface search 08 began at 0330 AST and ended at 0700 AST. This was a night search for illuminated life rafts using Litton night vision goggles model M915A (single image intensifier module). Some of the life raft lights became extinguished toward the end of the search due to drained batteries. South to southwest winds at 20 to 25 knots with significant wave heights of 1.8 to 2.0 m prevailed during the search. Visibility ranged from 6 to 12 nmi throughout the search. Following the completion of surface search 08, five of the seven lookouts complained of eye irritation from the night vision goggles.

Surface search 09, a daylight visual search, began at 0715 AST and ended at 1210 AST. The CCGS "Alert" stopped at 1025 AST and launched the FRC to repair the LORAN-C buoy antenna. Surface search 09 was resumed at 1132 AST. The differential LORAN system was still not operational, the problem being due to failure of the LORAN-C buoy. A southwest wind of 20 knots and significant wave heights of 2.0 m prevailed throughout the search. Visibility was 5 nmi in mist during most of the search.

The CCGS "Sir William Alexander" began servicing life rafts at 1300 AST in preparation for the next night search. She finished servicing life rafts at 1700 AST and proceeded into Chedabucto Bay for the night. During the afternoon, the CCGS "Alert" fixed the positions of all the life raft mooring locations.

Surface search 10 began at 1800 AST and ended at 0020 AST December 5. This was a night visual search for illuminated life rafts. It was decided not to use the night vision goggles for this search because of the numerous complaints of eye irritation after the last two searches with the goggles. Winds during the search were west to northwest at 30 to 39 knots with significant wave heights between 2.8 to 3.2 m. Visibility was reduced to 1/4 to 1/2 nmi in snow flurries at the beginning of the search and had improved to 8 nmi by the end of the search.

Monday, December 5, 1988

Surface search 11, a daylight visual search, began at 0830 AST and ended at 1200 AST. A westerly wind at 26 to 31 knots with significant wave heights of 2.4 to 2.7 m prevailed during the search. Visibility was beyond 15 nmi throughout. The vessel was accumulating ice due to freezing spray; the icing on the bridge windows was obstructing vision somewhat.

The CCGS "Alert" departed the Canso Bank upon completion of surface search 11 and arrived in Mulgrave at 1630 AST. The CCGS "Sir William Alexander" retrieved all the life rafts then proceeded to Mulgrave, arriving at 1745 AST. Some of the life rafts had collapsed canopies and damaged lights due to the seas and ice accumulation. All the NORDCO equipment and personnel were demobilized from the CCGS "Alert" and mobilized aboard the CCGS "Sir William Alexander". A meeting was held with Mr. Dawe of NORDCO to discuss the upcoming airborne searches. After the meeting, Mr. Dawe departed with Dr. P. Stager who returned to Toronto the following day.

The NORDCO personnel worked until 0100 AST servicing the life rafts and fitting them with radar enhancement devices. Truck inner tubes were lashed upright inside the life rafts to help support the radar reflectors and raft canopies.

Tuesday, December 6, 1988

The CCGS "Sir William Alexander" departed Mulgrave at 0700 AST for the Canso Bank. Enroute, NORDCO personnel completed the fitting of radar reflectors and transponders in the life rafts for the airborne radar searches. Deployment of life rafts began at 1100 AST. A total of nine life rafts were deployed at mooring positions 4,5,6,8,9,11,12,13, and 14. Eight life rafts had Lensref radar reflectors. The life raft on mooring 6 had a Chemring radar reflector and the life raft on mooring 4 had a radar transponder attached, in addition to the Lensref radar reflector. All life rafts were deployed by 1500 AST. The CCGS "Sir William Alexander" then proceeded to anchor in a position 0.5 nmi north of the LORAN-C buoy to serve as a fixed reference for the airborne searches.

Airborne search 02 began at 1521 AST and ended at 1703 AST. This search was conducted by the USCG from a Falcon Jet utilizing a Side-Looking Airborne radar (SLAR) and a Forward-Looking Airborne radar (FLAR). During the flight winds were west to west-southwest at 08 to 15 knots with significant wave heights of 1.2 m. Visibility was beyond 15 nmi under 1/10 cloud cover.

Airborne search 03 began at 2015 AST and ended at 2035 AST. This search was carried out by an Atlantic Airways Ltd. Beechcraft King Air using the Litton APS-504(V)5 Search radar. During the search the wind was west-southwest at 15 knots with significant wave heights of 1.2 m. The visibility was beyond 15 nmi under clear skies.

At 2040 AST, the CCGS "Sir William Alexander" departed the Canso Bank and anchored in the mouth of Chedabucto Bay at 2330 AST.

Wednesday, December 7, 1988

The CCGS "Sir William Alexander" weighed anchor at 0630 AST and proceeded to survey the status of the life rafts. The vessel arrived at the LORAN-C buoy at 0900 AST and maintained a position within 1/2 nmi of the buoy for the duration of the days airborne searches.

Airborne search 04 by the USCG began at 0935 AST and ended at 1138 AST. Airborne search 05 by Atlantic Airways Ltd. began at 1130 ADT and ended at 1330 AST. South to south-southwest winds at 31 to 34 knots with significant wave heights of 2.7 to 3.0 m prevailed throughout the two searches. Visibility was 10 to 15 nmi under overcast skies.

The CCGS "Sir William Alexander" proceeded to mooring 04 upon completion of airborne search 05 to check the radar transponder. No radar response was detected and the transponder's lamp extinguished. The CCGS "Sir William Alexander" then returned to take up its position at the LORAN-C buoy as a reference for the airborne searches.

Airborne search 06 by the USCG began at 1510 AST and ended at 1645 AST. Airborne search 07 by Atlantic Airways Ltd. began at 1735 AST and ended at 1905 AST. South-southwest to southwest winds at 22 to 32 knots with significant wave heights of 2.7 to 3.0 m were predominant during the two airborne searches. Visibility was 8 to 10 nmi, improving to 15 nmi during the last hour of airborne search 07. Skies were overcast during both searches.

Surface search 12 began at 1750 AST and ended at 2010 AST. This was a night search using Litton model M915A night vision goggles (two image intensifier modules). The Captain allowed only one seaman on the bridge as a lookout and used the quartermaster as the second lookout. The quartermaster's normal duties interferred somewhat with his duties as a lookout when using the night vision goggles. South-southwest to southwest winds at 22 to 32 knots with significant wave heights of 2.5 to 2.8 m were observed throughout the search. Visibility was 10-15 nmi.

Thursday, December 8, 1988

Surface search 13, a daylight visual search, began at 0815 AST and ended at 1016 AST. The captain provided two seamen as lookouts for this search but had them positioned on top of the bridge (monkey island). It is possible that the complete lack of shelter at the location may have affected how well the lookouts functioned, especially in harsh weather. North-northwesterly to northerly winds at 15 to 19 knots with significant wave heights of 1.6 m were observed throughout the search. Visibility was beyond 15 nmi. The maximum wind-chill temperature at the look out positions during the search was -15 degrees Celcius.

Following surface search 13 the CCGS "Sir William Alexander" proceeded to the LORAN-C buoy position to recover the buoy and mooring. The LORAN-C buoy and mooring was recovered at 1106 AST.

Airborne search 08 by Atlantic Airways Ltd. began at 1000 AST and ended at 1120 AST. Throughout the search winds were north to north-northwest at 12 to 17 knots with significant wave heights of 1.4 to 1.6 m. Visibility was greater than 15 nmi under 2/10 to 4/10 cloud cover.

Following airborne search 08 the CCGS "Sir William Alexander" began servicing the life rafts. The defective radar transponder was removed from the life raft on mooring 6 and another transponder was attached to the life raft on mooring 4. The only life raft lamps that could be relit were those on moorings 5, 11, and 12. The life raft lamps on the remaining moorings had been severely damaged by seas and ice accumulation.

Surface search 14 began at 1700 AST and ended at 2150 AST. This was a night search for illuminated and unilluminated life rafts using Litton model M915A night vision goggles (two image intensifier modules). The lookouts were located on top of the bridge for the duration of the search. West-northwest to north winds at 12 to 20 knots with significant wave heights near 1.2 m were observed during the search. Visibility was 15 nmi or better. The maximum wind-chill temperature at the lookout positions was -14 degrees Celcius.

Airborne search 09 by Atlantic Airways, the final airborne search, began at 1725 AST and ended at 1902 AST. West-northwest to north winds at 12 to 20 knots with significant wave heights of 1.2 metres were observed during the search. Visibility was over 15 nautical miles under cloud cover ranging from 3/10 to 9/10.

Friday, December 9, 1988

Surface search 15, a daylight visual search, began at 0800 AST and ended at 1200 AST. Under the Captains direction, the lookouts were again assigned positions on top of the bridge for the complete search. Northwest winds at 25 to 34 knots with significant wave heights of 2.1 to 2.3 m prevailed during the search. Visibility was over 15 nmi. The maximum wind-chill temperature at the lookout positions was -25 degrees Celcius.

During surface search 15, several discussions were held between Mr. R. Fitzgerald aboard the CCGS "Sir William Alexander" and Mr. B. Dawe in St. John's regarding the continuation of the experiment. Based upon an assessment of events, forecasted environmental conditions, the condition of the life rafts and accumulated data, it was decided to terminate the experiment after the completion of the search.

One of the original purposes of this year's experiment was to collect SAR target detection data from a SAR vessel (CCGS "ALERT") with different motion characteristics and height of eye. These results could then be compared with those obtained in 1987 for a vessel (CCGS "Sir William

Alexander") that was a more stable platform and having a greater height of eye. Unfortunately data collection with the CCGS "Alert" had to be terminated earlier than planned due to serious mechanical problems. It was then decided to transfer to the CCGS "Sir William Alexander" mainly to support the airborne radar searches and to accumulate more data for night visual searches from this vessel. Also there was the possibility of collecting data for visual day searches in environmental conditions varying from that of the previous year. The airborne phase of the experiment was completed successfully but night searches were proving to be a problem because of the rapid deterioration of the life rafts, particularly the lighting equipment. In order to continue with night searches for illuminated targets all the rafts would have to be sent ashore to a life raft servicing facility to have new lamp sockets installed. This seemed impractical due to time limitations. Further, the environmental conditions (wind, seas, freezing spray and ice accumulation) which caused the problem were not expected to improve as the season progressed.

The CCGS "Sir William Alexander" began retrieving liferafts and moorings at 1230 AST. She finished recovery of moorings 4,5,6,8 and 11 by 1520 AST and then proceeded into Chedabucto Bay for the night.

Saturday, December 10, 1988

The CCGS "Sir William Alexander" arrived on the Canso Bank at 0900 AST and began recovery of the remaining moorings. The recovery of moorings 9,10,12,13,14 and the wave buoy was completed by 1200 AST. The CCGS "Sir William Alexander" then departed the Canso Bank for the CCG Dartmouth base, and arrived at 2230 AST. Mr. Fagan, Mr. McCarthy, and Mr. Russell disembarked to return to St. John's.

Sunday, December 11, 1988

Mr. Tucker and Mr. Fitzgerald remained aboard and demobilized NORDCO equipment.

Monday, December 12, 1988

All NORDCO equipment was offloaded from the CCGS "Sir William Alexander" into a rental truck. Mr. Tucker and Mr. Fitzgerald departed the CCG Dartmouth base at 1100 AST via the rental truck enroute to St. John's.

End of Part II

APPENDIX C

SUMMARY OF ENVIRONMENTAL CONDITIONS

ENVIRONMENTAL CONDITIONS

DAYTIME VISUAL SEARCHES

#	VISIBILITY (nmi)	WIND (T. Kts)	HS(m)	NOTES
3	1 1/2 DCRG 1/4	SE 35 BCMG SSW 20	3.3 INCR 4.4	WIND WAVE ONLY 2h R-,R
5	15	W 25 BCMG WNW 30	2.4-2.6	1.5-2.3m WIND
13	15+	NNW-N 12-19	1.4 - 1.6	WAVE + WSW SWELL
6	15	W-WSW 29	2.5-2.6	MAINLY WIND WAVE 1h SP--, RW--
9	12 DCRG 5	SW 18-21	2.3 DCRG 2.0	WIND WAVE ONLY 2 h MIST
11	15+	W 26-31	2.7 DCRG 2.0	WIND WAVE ONLY 1.0m WIND WAVE + SSW SWELL
15	15+	NW 34 DCRG 25	2.4 DCRG 2.1	WIND WAVE ONLY

NIGHT TIME VISUAL SEARCHES

10	1/4 INCR 8	NW 39 BCMG W 30	2.8 INCR 3.2	WIND WAVE ONLY 1h S,S+

NIGHT VISION GOGGLE SEARCHES

1	15-15+	S 7 INCR 26	0.6 INCR 1.1	0.0-1.1m WIND WAVE + WNW SWELL
2	15 BCMG 7	S 26 BKG SE 25-30	1.1 INCR 2.2	1.1-2.0 WIND WAVE + SLY SWELL, 0.5h R-
4	15	WSW 20-26	3.1 DCRG 2.8	0.6-0.9m WIND WAVE + SW SWELL
7	15+ BCMG 10	W 18 SHFTG SSW 15-25	1.6-1.9	WIND WAVE ONLY 0.5 R-, RW-
8	6-12	S 25 BCMG SW 20	1.9-2.0	WIND WAVE ONLY 0.5h MIST
12	10 BCMG 15	SSW-SW 22-32	2.5-2.8	WIND WAVE ONLY

14	15-15+	WNW-N 12-20	1.1-1.3	0.6-0.9m WIND WAVE + SW SWELL

AIRBORNE RADAR SEARCHES (Atlantic Airways)

#	WIND (T.kts)	HS(m)	NOTES
A1	S 25	1.5	
A3	W SW 15	1.2	WIND WAVE ONLY
A5	S 32-34	2.9-3.0	WIND WAVE ONLY
A7	SSW-SW 22-32	2.5-2.8	WIND WAVE ONLY
A8	NNW-N 12-17	1.4-1.6	0.8-1.0m WIND WAVE + SW SWELL
A9	NW-N 13-20	1.2-1.3	0.7-0.9m WIND WAVE + SW SWELL

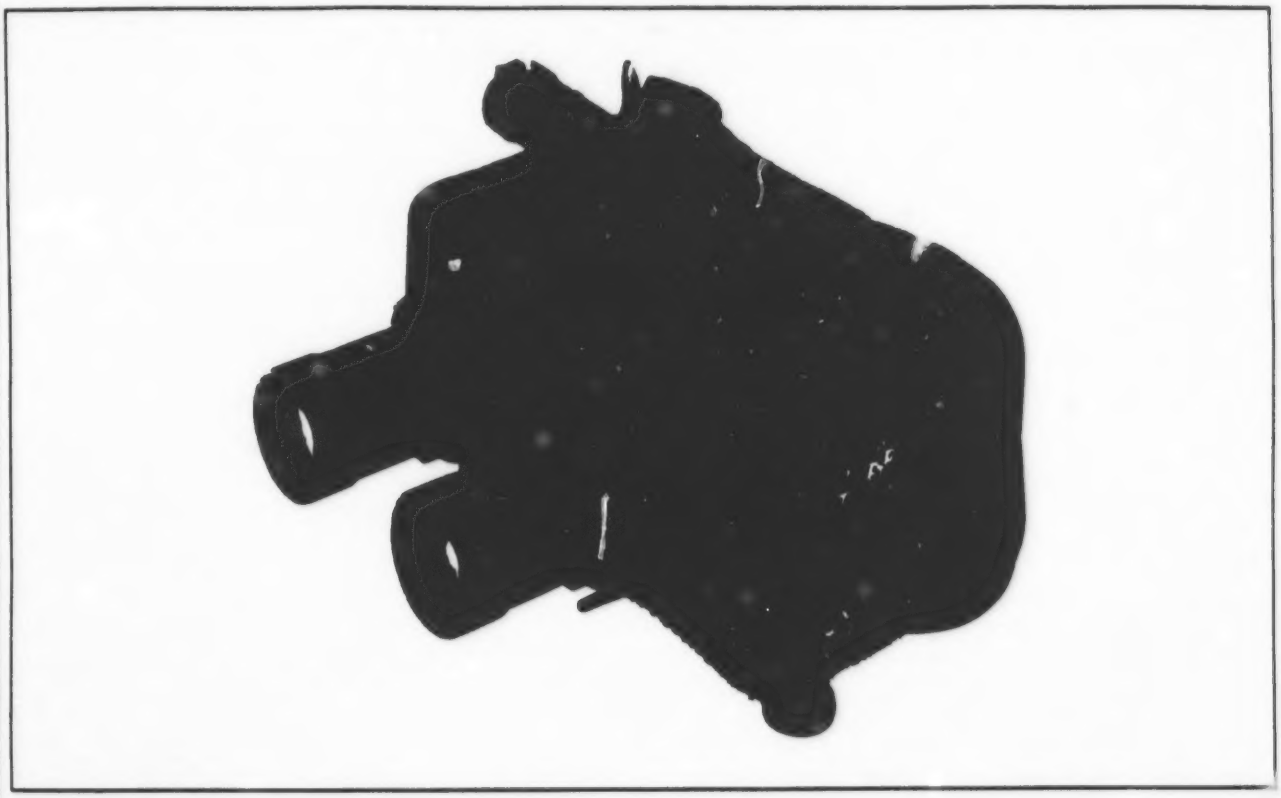
AIRBORNE RADAR SEARCHES (USCG)

A2	W-WSW 8-11	1.1-1.2	0.3m WIND WAVE + WLY SWELL
A4	SSW-S 31-34	2.7 INCR 2.9	WIND WAVE ONLY
A6	SSW 22-25	2.7-3.0	WIND WAVE ONLY

APPENDIX D

NIGHT VISION GOGGLE BROCHURES

LITTON MODEL M-912A/M-915A HIGH PERFORMANCE NIGHT VISION GOGGLE



The Litton Models M-912A and M-915A Night Vision Goggles are completely self-contained night vision systems providing passive viewing capability under moonlit or starlit conditions.

These systems are improved versions of the U.S. Military AN/PVS-5A. Both the M-912A and the M-915A operate on two "AA" batteries.

Features

- Stronger facemask material than AN/PVS-5A
- Improved objective lens design
- AA battery configuration allows use of commercially available batteries
- Meets or exceeds all applicable specs of MIL-N-49065
- Lithium AA battery available for low temperature operation
- Available with optional soft carrying case
- Standard accessories and optional equipment as available for AN/PVS-5A & AN/PVS-5B

These new models incorporate a higher output infrared source for situations where there is no light or extremely low light. It can be switched on whenever needed for map reading, vehicle repair, dark building or bunker use, and other tasks for viewing at ranges up to 6 meters.

Applications

- Vehicle driving
- Patrols
- Security
- Surveillance
- Drug traffic control
- Search and Rescue
- Utility power line inspection and repair
- Supersensitive film manufacture/processing
- Nocturnal wildlife surveillance

NORDCO LIMITED

LITTON MODEL M-912A/M-915A
HIGH PERFORMANCE NIGHT VISION GOGGLE

Image Intensifier

The M-912A utilizes two 2nd Gen wafer type image intensifier tube assemblies, each having an 18mm image format. Each assembly has its own power supply to provide redundancy for improved reliability.

The M-915A is a high performance version of the M-912A and employs two 18mm Gen 2^{plus} image intensifier assemblies which gives the system three times the system gain of the standard AN/PVS-5A, and a dramatic increase in useful range.

The improved flash performance and extended dynamic range of the M-915A allows its use under field conditions previously too harsh for night vision systems. The image detail stays clear and bright, even when flares or bright lights are flashed directly into the field of view.

Typical System Characteristics	Values	Units
General		
Magnification	1.0X	
Field of view	40	degrees
Resolution (limiting)	.68	Lp/mR
Brightness gain (M-912A)	1000	
(M-915A)	1700	
Weight	960	grams
Objective Lens		
Focal Length	26.8	mm
F/Number	1.1	
T/Number	1.2	
Focus Range	25 to infinity	cm
Eyepiece		
Effective Focal Length	27.0	mm
Diopter Range	−6 to +2	diopter
Eye Relief Distance	15.0	mm
Interpupillary	51 to 72	mm

Electrical

Power source: (2) 1.5 V Alkaline Batteries
Operating life: 40 hours @ 23 degrees C

Environmental

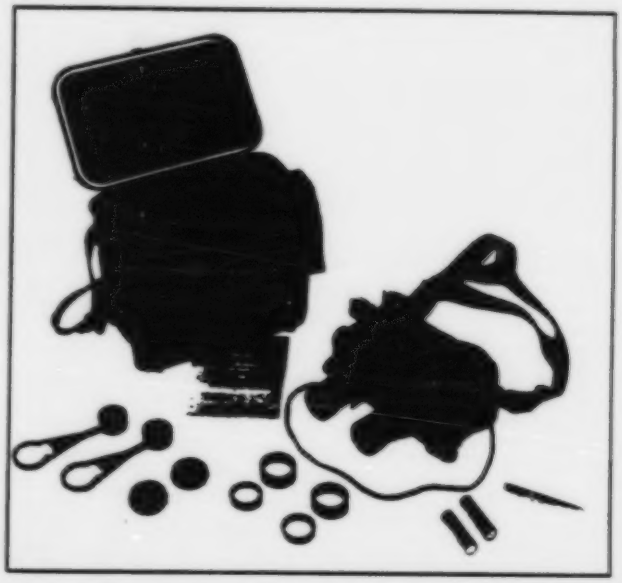
Temperature,
operation: −51 degrees C to +49 degrees C
storage: −51 degrees C to +68 degrees C
Humidity: 95% @ +68 degrees C
Water Immersion: 1m for 30 min.

Standard Accessories

Night Vision Goggles, black with neck cord
Carrying Case, Polycarbonate plastic, black with strap
Head strap, black
Instruction Manual
Lens Cleaning Tissue
Hexagonal Wrench key, .050"
Batteries, two BA-3058/U
Lens Protective Caps

Optional Equipment

Shipping Storage Case
Demisting Shields
Daylight Training Filters (2)
Lithium AA Batteries
Sacrificial Filters (2)
Soft Carrying Case



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For a more detailed technical discussion of your application, please contact your local Litton representative or write to Litton Electron Devices, 1215 South 52nd St., Tempe, AZ 85281 USA.

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NORDCO LIMITED

LITTON MODEL M-972 HIGH PERFORMANCE NIGHT VISION GOGGLE

The Model M-972 Night Vision Goggle is a lightweight, single-tube, high gain, night vision goggle manufactured to meet US Government standards. This rugged, water-resistant model will be the new US Government standard one-tube Night Vision Goggle.

Features

- High gain
- Small compact, light weight
- Long eye relief
- Built-in infrared illuminator
- Usable with protective mask
- Five-position rotary "ON" "OFF" switch
- Quick face mask disconnect with auto "OFF"
- Detached hand-held operation
- Uses standard "AA" batteries, or standard US Military BA-1567/u or BA 5567/u.
- Easily upgradable to Gen 3
- LED "ON" warning light
- Convertible to 3X or 4X binocular*

*Under development

Litton's Night Vision Goggles are used by military, para-military and police forces worldwide. Typical applications include general night surveillance and observation, night maintenance and map reading, and highly mobile operations such as anti-terrorist squads, commandos, or special forces. Other applications are listed below.

Applications

- Nocturnal observations
- Covert security surveillance
- Patrols/military-law enforcement
- Search/pursuit
- Drug control
- Maritime navigation aid
- Nocturnal entomology
- Low light level inspections
- Film processing/manufacturing security
- Nocturnal wildlife surveillance
- Scientific and astronomical
- Retinitis pigmentosa vision aid
- Utility power line inspection (corona inspection/detection)

NORDCO LIMITED

LITTON MODEL M-972
HIGH PERFORMANCE NIGHT VISION GOGGLE

Image Intensifier Tube

The M-972 utilizes the latest high performance version of the Gen 2+ 18mm proximity focus image intensifier assembly. This tube assembly has been designed with maximum flexibility for use in night vision applications requiring higher resolution, higher light amplification and higher output brightness than that normally available for standard Gen 2 18mm image intensifiers.

Housing

The M-972 housing material is a high tensile strength plastic alloy. Assembly is designed to allow simple maintenance with a minimum of special tools. The housing has a purge valve for system purge during maintenance.

Objective Lens

f/1.2 High Performance Lens, compatible with Gen 2+ or Gen 3 image intensifier assemblies.

Eyepiece Viewer Assembly

- Has 25mm eye relief
- Compatible with protective mask
- Usable with eyeglasses
- Eyecup and demist shield can be fitted

A variety of innovative features have been added to allow full utilization of the product's high performance in commercial or military applications. An auxiliary feature is ability of upgrade to 3X or 4X surveillance binocular by simple objective lens change.*

*Under development

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Specifications

General	Nominal Values	Units
Magnification	1.0X	
System Gain, Nominal	1850	Ft. L/Ft. L
Field of View	40	Degrees
Resolution, limiting, (on axis)	0.68	1p/mR
Objective Lens		
Focal Length	27	mm
F #	1.2	
Focus Range	25 cm to infinity	
Eyepiece		
Effective focal length	27	mm
Diopter Range	−6 to +2	Diopter
Eye Relief Distance	25	mm
Pupil Diameter, minimum at ERD	8.0	mm
Interpupillary range	55 to 71	mm
Mechanical (System)		
Weight (no batteries)	700	Grams
Operating Time using full capacity Alkaline "AA" batteries	40	Hours

Standard Accessories Included with M-972

Carrying Case P/N207792-100
Lens Cleaning Tissue
Operators Manual
Lens Cap
Facemask
2 "AA" Batteries

Optional Accessories

Shipping/Storage Case P/N207793-100
Sacrificial Filter P/N207794-100
Demist Shield (2 ea. required)
Eyecup (2 ea. required) P/N208014-100
Daylight Training Filter P/N207064-100

For a more detailed technical discussion of your application, please contact your local Litton representative or write to Litton Electron Devices, 1215 South 52nd St., Tempe, AZ 85281 USA.

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APPENDIX E

HUMAN FACTORS REPORT

VISUAL SEARCH VARIABLES IN MARINE SAR OPERATIONS: A HUMAN FACTORS PERSPECTIVE

MARCH, 1989

BY
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CONSULTANT IN HUMAN FACTORS
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1. INTRODUCTION

Initial observations were made on board the Canadian Coast Guard Ship (CCGS) "Alert" November 20-21, 1989, and experimental visual search trials being conducted by NORDCO Limited personnel on the Canso Bank were monitored December 3-5. Both day and night visual searches for moored life rafts were observed. The bridge of the CCGS "Sir William Alexander" was inspected briefly December 5, 1989.

The observations made at these times have been summarized in terms of (a) the general validity issues of the detection data collected during the trials, (b) the workstation and equipment available to the seamen, (c) the procedures followed in visual search operations, and (d) the recommendations that might be considered by CCG SAR planning and resource development staff. The observations and comments that are included in this report thus pertain not only to the experimental trials but also to other searches that may be conducted from the CCGS "Alert" or from the CCGS "Sir William Alexander".

2. VALIDITY ISSUES FOR THE NORDCO LIMITED DETECTION DATA

In examining the visual detection data, consideration may be given to relevant variables that are either related to search procedures or to individual differences between subjects.

For example, from conversations with the participating subjects, it was apparent that each subject followed a different scan pattern. The absence of a standardized scanning pattern could not at this point be said to have affected the detection results but the lack of control on scanning technique does leave open the question of general applicability of the data.

During the observation period, there was a significant variation in the meteorological conditions but relatively few detections or data points. It may be difficult therefore to statistically relate detection probability and visibility. The combination of the wave height and the pitch envelope of the vessel acted to reduce the average exposure time when the targets were visible to lookouts. However, unlike airborne visual searching, the targets continue to be potentially visible for extended periods of time. The net effect with increased wave height would be that the detection range is reduced. The reduction in sweep width occurs because the target is exposed for a smaller percentage of time and not necessarily because of a perceptual limitation per se. Apart from the motion effects that may be induced by the lack of stability of the "Alert", the degree of pitch and roll experienced by the vessel would tend to reduce the range at which detection occurred. Indeed, it may be difficult to satisfactorily partial out the effects of these two sources of variance in the data. The "Sir William Alexander" provides a greater vertical viewing angle which would also tend to reduce the effect of wave height, particularly at reduced sweep widths. These variables are extremely significant for the development of an optimal scanning strategy to be used by lookouts during both day and night searches. The role of an optimal scanning pattern apparently has not been rationalized in the present context.

In terms of subjects, there may be some question whether the participants were a representative sample of potential observers from the point of view of experience, motivation, and visual capability. For example, individual differences in visual contrast sensitivity can be shown to affect significantly detection probabilities (Ginsburg, 1986; Stager and Hameluck, 1986). Subject comfort and fatigue while on station and the varying level of dark or light adaptation of the subjects under certain conditions could also affect detection performance. On-site observations relating to these variables are considered in this report although direct measures of these subject variables are not available to assist in the interpretation of the data. It is recommended that the data be examined subject by subject to determine within-subject effects across conditions.

Experience with research in airborne SAR operations has underlined the inherent difficulty of accounting for many of the variables that are known to operate in the visual search task. These factors include components such as sun angle, the relative position of the sun, colour contrast, brightness contrast, contextual embedding, slant range, target occlusion, and others. It is extremely difficult to be able to account for the variety of variables and undertake a project that remains manageable. In airborne search, target contrast has proven to be the most salient characteristic associated with higher levels of visual detection. The data analysis should seek to minimize the number of variables required to account for the greatest percent of variance.

3. WORKSTATIONS AND EQUIPMENT

There were marked contrasts in the workstations on the "Alert" and on the "Sir William Alexander" and each can be addressed separately.

3.1 COGS "Alert"

The bridge on the "Alert" was not designed for sustained visual search operations. When binoculars were used in day searches, virtually all subjects were observed to lean or rest their elbows on the narrow ledge below the windows that encircle three sides of the bridge. The ledge is an inappropriate height for this posture and forces the subjects into a posture that cannot be sustained over prolonged periods without discomfort. The bridge windows present a continuous field of view (FOV) except for a narrow pillar at the corners and two larger posts on either side of the centre control console. The subjects were observed to move to the side when a view greater than 70^{O} to port or starboard was required but with the narrow corner posts, it was possible to obtain overlapping FOVs forward and laterally. The use of night vision goggles required that the front or side windows in front of each observer be open. This exposure to the cold outside air made the search task distinctly uncomfortable. There is no discussion in the earlier NORDCO Limited report (Dawe, Finlayson, and Bryant, 1987) about the sector of the observers FOV most frequently associated with detection although it would likely be in the $45 - 60^{O}$ range. There should be less likelihood of a dichotomous distribution of probability of detection and bearings for FOV in data collected on the "Alert" than on the "Sir William Alexander". During night searches, the starboard lookout experienced more reflections on the windows than the port lookout because the lighting for the navigation table was immediately aft. The reflection provided a significant distraction to the observers and could be eliminated with attention to the curtain system.

3.2 COGS "Sir William Alexander"

The FOV available for the lookouts on the bridge is more restrictive than the FOV in the "Alert". The transition from forward to side viewing is made difficult by a short section of side wall between each side window and there is a glass door at each forward corner (ie., on the front face) of the bridge. The door may be used for searching but it does not provide an armrest of any sort. The adjacent windows are not slanted forward like those in the "Alert" and restrict the FOV. The effective FOV for the port lookout would be expected to be between -60^{O} and $+20^{O}$ with a comparable FOV for the starboard lookout. Approximately 5^{O} of the viewing sector is blocked by the A-frame superstructure. Like the "Alert", the "Sir William Alexander" provides a grab bar below the windows and a narrow window ledge. The width of the ledge would appear to make it more unsuitable for support than the one provided in the "Alert".

In some applications, it is appropriate to use motion-stabilized binoculars to null out nearly random oscillations but they would not be particularly effective in the present context. Night-vision goggles are useful but problems with their use have been observed. The FOV for the goggles would appear to be in the order of 40^{o} and any scanning pattern that is adopted should take the restricted FOV into account. Dawe, Finlayson, and Bryant (1987) have reported on the negative comments they received concerning the weight of the goggles. In the most recent trials, five of six seamen reported that they had experienced watering of the eyes when using the goggles. The watering may have been caused by a faulty adjustment in the goggles or by the observers exposure to the cold air at the open window.

The lack of appropriate seating, the uncomfortable posture assumed in order to steady binoculars or night-vision goggles, restricted FOV in the goggles, prolonged exposure to cold temperatures, and mild nausea that is related to the stability of the vessel are all factors that would degrade visual detection performance.

4. VISUAL SEARCH PROCEDURES

Conversations with the lookouts indicated that individuals had developed their own methods. One lookout, using night-vision goggles in snow, reported scanning across the horizon and then reversing the direction of the scan. The reverse scan followed a saw-tooth pattern, coming in from the horizon and then out again. Another divided the FOV into thirds and then scanned each third back and forth, working his way in toward the ship. Scanning would likely be more effective if range limits had been given to the lookouts but this could not be done within the experiment. On the other hand, the lookouts did not receive explicit instructions to the contrary but it is assumed that they followed previous practices. Does visual scanning in operational marine searches extend to the horizon or to the limits of visibility without restriction?

Lookouts were on station for periods of 2 hours. It would be expected that detection performance would not be consistent for the duration and would decline after an hour. In airborne searches, prolonged periods on duty will have the effect of reducing the probability of detection since the target is exposed for a severely limited period of time (i.e., a matter of seconds). In marine searches, lower detection performance is probably manifested as a reduction in the detection range. At least one lookout who was using binoculars during a day search was observed to put the binoculars aside, close his eyes, and rest for several minutes. This practice may be necessary under the conditions of marine visual search but becomes of greater concern with narrower sweep widths.

In the operational marine environment light and dark adaptation is of some concern. For example, dark adaptation occurs over a period of approximately 20 to 30 minutes. In night searches, therefore, detection probabilities will be reduced when lookouts first assume watch after being on a break. Ideally, the brightness should be reduced in the night-vision goggles as the adaptation process takes place. Similarly, light adaptation is required on day searches when lookouts come onto the bridge but the negative effects are minimized with the relatively long detection "window" that is available in marine searches.

The longer detection window could argue for searches being conducted at a greater speed. During daylight searches, the Alert was travelling at approximately 9 knots. The rate could be increased without significantly reducing detection levels but it is understood that this rate was governed by the power configuration of the "Alert".

Lookouts were requested to provide range and bearing estimates when a detection was reported but the information available from the radar display indicated that the range estimates were too high. This observation does not impact on the validity of the experimental data because the actual values will be available for analysis. There is a procedural concern,

however, that if a target in an actual search was to be detected and then lost it may be very difficult to then relocate the target and retrieve it without a more accurate range estimate.

5. RECOMMENDATIONS

The following summary recommendations have been drawn from the human factors observations.

1. Undertake a research project to develop an optimal visual scan pattern for the marine environment that takes into account known limitations in human visual search capabilities.

Observations during the visual search trials and review of the USCG report on scanning techniques used by lookouts (Blackwell, Osmer, Simmonds, Everson, and Watson, 1982) reinforces the perceived need to develop a standard scanning pattern that can be adapted to the variety of marine search conditions that are encountered. Stager and Angus (1975, 1978) have earlier proposed scanning patterns appropriate for airborne search. They were intended to replace the patterns that have been retained in SAR manuals without validating research. A similar study should be undertaken to develop a procedure for the marine environment. (Note that the absence of a consistently applied pattern would tend to reduce the generality of the detection data acquired in the NORDCO search trials and, in general practice, would limit the applicability of standard POD values in a computer order search program system).

2. Develop an effective training program in visual search methods (including training experiences and manuals) and a means for periodic performance evaluation of CCG personnel responsible for visual search.

The development of a valid scanning pattern has to be accompanied by a rigorous training program for potential lookouts that will ensure their use of correct visual search methods for consistent and effective scanning. The training program should increase an awareness of limitations on visual search so that lookouts can recognize the existence of conditions that would degrade their performance. Experience with visual search in the Canadian SAR context underlines how difficult it is for SAR personnel to maintain a consistent pattern in the absence of concrete feedback (ie, a dynamic display of their actual scan patterns) and reinforcement.

3. Undertake an experimental program to investigate the effect of contrast sensitivity on POD values associated with marine searching.

Consideration should be given to undertaking a program to investigate the effect of contrast sensitivity (Ginsburg, 1986) on detection levels. Stager and Hameluck (1986) found that contrast sensitivity was related to the probability of detection for SAR visual search for ground targets and have suggested that SAR personnel might be selected for visual searching at least partly on their measured contrast sensitivity. Note that it might be appropriate to think in terms of distinguishing between a primary and secondary roster as a function of contrast sensitivity should the measure turn out to have high predictive valudity in the marine environment. In an

earlier USCG study of human factors in SAR (Remondini, Light, Everson, Nash, Good, and Osmer, 1982) the probability of detection was related to the performance of lookouts on a hidden figures and a hidden pattern test. There was a positive but marginal relationship reported between detection and the perception tests in spite of the questionable applicability of the tests. There are sufficient research data available which argue for continued investigation of the contrast sensitivity measures.

4. Undertake a limited research program to determine the optimal search time, including active lookout time on station, that can be expected of lookouts without degrading POD performance.

Consideration should be given to reducing the time that the lookouts are on station. In airborne searches over land, the Canadian SAR personnel are rotated at intervals of less than 30 minutes. It can be argued on the one hand that the visual complexity of terrain searches contributes to visual fatigue more quickly. By the same token, an argument can be made that the complexity serves to provide greater visual stimulation (than is encountered in the marine environment) and that visual attention can be maintained for a relatively longer period of time than would otherwise be the case. Remondini et al. (1982) also indicated that detection tended to decrease with time on watch for cutters and utility boats. Lookouts might alternate between port and starboard stations during their watch in order to increase the variety of visual stimulation and to change the direction of visual conditions to which they are exposed. These variations may help to maintain visual alertness.

5. Undertake a program to modify existing workstations for lookouts using known human factors standards.

Observations of the NORDCO search trials indicated the need to provide improved workstations for the lookouts, particularly in aversive conditions. This requirement would still be valid if the time on station were to be reduced as proposed in recommendation 4. The difficulties imposed on visual search by the existing stations as noted on the CCGS "Alert" and the CCGS "Sir William Alexander" have been described in Part 3. These included the absence of appropriate postural supports, restricted viewing ports, reflections on the view ports, exposure to elements, and the requirement to change dark/light adaptation between time on station.

Existing workstations for lookouts could be modified (depending upon the current configuration of the ship/bridge) to include:

(a) heating of windows in the bridge and particularly those to be used by lookouts to reduce the potential for icing or fogging during visual search;

(b) upper body and arm support that is adjustable for height;

(c) provision of a removable sit-stand stool that supports a posture integrated with the upper body support; and,

(d) provision of an unobstructed corner window (This might require the installation of a window blister (with a sit-stand stool and upper body support in the bridge) or a blister structure on the face of the bridge that could accommodate the lookout and an appropriate chair. (Note that visual airborne reconnaissance and search in the USCG, USAF, and CAF is undertaken with spotters in chairs that are installed at a blister side-window.))

6. Continue to investigate the use of night-vision goggles for SAR searches.

Some difficulties in using the night-vision goggles were observed during the NORDCO search trials. The lookouts had received a briefing on the use of the goggles at the beginning of the experimental trials but may not have followed the recommended procedures fully. One of the potential difficulties noted generally during the trials was the variation in lighting to which the lookouts were exposed during their duty time. It is mostly likely that dark adaptation would be lost during the breaks between time at their station. Acquiring and maintaining dark adaptation is a critical variable for the use of the night-vision goggles. The validity of the data obtained with the goggles to date may be questioned and additional carefully monitored trials may be warranted.

7. Prepare a standard operating manual for visual search procedures and ensure adherence to the recommended procedures.

A Search and Rescue Unit (SRU) is allocated to the search task to find and aid those in distress. Perhaps it is because the operation of the SRU and its equipment is both visible and measurable that greater effort is expended on maintaining a certain level of performance and reliability in the use of the equipment than in the performance of the lookouts. While there is a continuing effort to reduce the dependence on human search and to depend more on electronic and radar detection, there will likely continue to be the requirement for efficient visual search. The conduct of visual search is costly and time consuming and all possible measures, including the adherence to published procedures, should be encouraged.

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